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October 1994

INVESTIGATION OF THE IONOSPHERIC

SHORT-TERM VARIABILITY

Final Technical Report

by

ZWI HOUMINER

September 1993 - August 1994

United States Army

EUROPEAN RESEARCH OFFICE OF THE US ARMY

London, England

Contract number: DAJA-93-C-0035

Principal Investigator: Prof. G. Shaviv

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Technion, Haifa 32000, Israel

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ABSTRACT

Both the total electron content of the ionosphere (TEC) and the critical frequency of the F2 layer (foF2) exhibit large day-to-day variations during quiet and active geomagnetic periods. It is of great interest to ascertain whether good correlation exists between TEC daily variability about the monthly mean and foF2 variations. With the availability of the global GPS constellation to provide instantaneous time-delay values such a correlation may enable the improvement of HF short-term predictions using passive monitoring of TEC.

To determine the correlation, a pilot study was conducted using several months of TEC data taken in Haifa, Israel during 1980 as well as GPS time-delay measurements taken during the summer of 1992 in Jerusalem, Israel. The corresponding foF2 measurements were from Cape Zevgary, Cyprus.

The analysis showed, that for large percentages of the time very good correlation exists between TEC and foF2 short-term variations. The correlation coefficient varies from 0.7 - 0.8 during winter and summer months to about 0.5 - 0.6 during equinox months. A study of the diurnal dependence of the correlation indicates that better correlation exists during day-time than night-time. There was no indication that the correlation coefficient is dependent on geomagnetic activity during the period of this study.

The high correlation between TEC and foF2 in the limited data analysed, indicates, that real-time ionospheric HF prediction improvements are feasible when using transionospheric time-delay measurements.

KEY WORDS

Ionospheric variability; HF propagation; HF short-term predictions; Total electron content (TEC); foF2; Transionospheric time-delay; GPS.

TABLE OF CONTENT

1. INTRODUCTION

To assess the possible improvement of HF short-term predictions from transionospheric time-delay measurements, it is of great interest to ascertain whether good correlation exists between TEC daily variability about the monthly mean and foF2 variability. To determine such correlation, a pilot study was conducted using several months of TEC data taken in Haifa, Israel during 1980 as well as GPS time-delay measurements taken during the summer of 1992 in Jerusalem, Israel. The corresponding foF2 measurements were from Cape Zevgari, Cyprus.

The TEC at Haifa was determined from Faraday rotation observations using the signal of the Sirio satellite. The geographic subionospheric point corresponding to a mean ionospheric height of 350 km (along the signal path) is 30.3°N and 28.9°E. The geographic coordinates of Cape Zevgari are 34.6°N and 32.9°E. The measurements are thus seperated by 4.3° in latitude and 4° in longitude. The GPS observations were taken at the National Physical Laboratory in Jerusalem using a Ionospheric Measurement System developed at the National Institute of Standards and Technology (NIST) at Boulder, Colorado for accurate time transfer. This system provides 15 minutes averages of time-delay data to all GPS satellites above the horizon. The equivalent TEC from the time-delay measurements was determined only for satellites at elevations larger then 30° and having a subionospheric point along the line of sight within 5° of the latitude of the ionosonde. The observed time-delays were then corrected for satellite biases converted into vertical TEC and averaged to obtain hourly values.

2. THE EXPERIMENTAL RESULTS

For each month analyzed, the varability of both the TEC and foF2 was determined. The variability is calculated by subtracting the monthly average value from each hourly value and deviding by

the monthly average value. Using the hourly values of the variability, a cross-correlation analysis between the TEC and foF2 was performed as well as auto-correlation for both TEC and foF2. Finally,the variability of the slab-thickness τ, determined from the ratio TEC/$(\text{foF2})^2$, was calculated.

The full account of the data analysis and the results obtained are summerised in the paper "Assessment of foF2 Short-term Variations from Transionospheric Time-delay Measurements" to be published in the Proceedings of the International Beacon Satellite Symposium, which took place at Aberystwyth, Wales, from 11-15 July 1994. The preprint of the paper is given in Appendix A.

A complete set of figures for each month analyzed in this study are given in Appendix B. The following figures are shown for every month:

a. Hourly values of the variability of foF2 and TEC.
b. Cross-correlation function between hourly values of foF2 and TEC.
c. Auto-correlation functions for foF2 and TEC.
d. Hourly values of the variability of the slab-thickness τ.

For the period June-August 1992 the results of smoothing the hourly values of foF2 and TEC by a 3-hour and 5-hour running mean, are also shown. The smoothing remarkably improved the correlation between foF2 and TEC, which is discussed in the paper in appendix A.

3. CONCLUSION

The high cross-correlation (>0.75) coefficient for foF2 and TEC in the limited data presented here raises the possibility that real-time TEC measurements may be used to update foF2 value determinations. The cross-correlation may even be higher if the geographic subionospheric point of the TEC measurement is closer

to the geographic point of the foF2 measurement, which introduces an error, in addition to the possible inherent measurements uncertainties. TEC measurements utilizing satellite emitted signals are passive in nature and do not burden the electromagnetic spectrum. In addition, the availability of the global GPS constellation to provide instantaneous time-delay, or equivalently TEC, values could provide an instantaneous updating of foF2 models on a global basis as well as on a regional basis. Such capability is important for HF communication along short, medium and long range paths.

4.LIST OF PUBLICATIONS

Z. Houminer & H. Soicher, "Improvement of foF2 short-term predictions from transionospheric time-delay measurements." National Radio Science Meeting, University of Colorado, Boulder, 5-8 January 1994.

H. Soicher & Z. Houminer, "Real-time ionoshperic HF prediction improvements by passive means." 19th Army Science Conference, Orlando, Florida, 20-23 June 1994.

Z. Houminer & H. Soicher, "Assessment of foF2 short-term variations from GPS time-delay measurements." International Beacon Satellite Symposium, Aberystwyth, Wales, 11-15 July 1994.

APPENDIX A

"Assessment of foF2 short-term variations from transionospheric time-delay measurements".
Proceedings of the International Beacon Satellite Symposium, September 1994.

ASSESSMENT OF f_oF_2 SHORT-TERM VARIATIONS FROM TRANSIONOSPHERIC TIME-DELAY MEASUREMENTS

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1. INTRODUCTION

To assess the possible improvement of HF short-term predictions from transionospheric time-delay measurements, it is of great interest to ascertain whether good correlation exists between TEC daily variability about the monthly mean and f_oF_2 variability. To determine such correlation, a pilot study was conducted using several months of TEC data taken in Haifa, Israel during 1980 (Soicher et al., 1982) as well as GPS time-delay measurements taken during the summer of 1992 in Jerusalem, Israel. The corresponding f_oF_2 measurements were from Cape Zevgari, Cyprus.

The TEC at Haifa was determined from Faraday rotation observations using the signal of the Sirio satellite. The geographic subionospheric point corresponding to a mean ionospheric height of 350km (along the signal path) is 30.3^{o}N and 28.9^{o}E. The geographic coordinates of Cape Zevgari are 34.6^{o}N and 32.9^{o}E. The measurements are thus separated by 4.3^{o} in latitude and 4^{o} in longitude. The GPS observations were taken at the National Physical Laboratory in Jerusalem using a Ionospheric Measurement System developed at the National Institute of Standards and Technology (NIST) at Boulder, Colorado for accurate time transfer. This system provides 15 minutes averages of time-delay data to all GPS satellites above the horizon. The equivalent TEC from the time-delay measurements was determined only for satellites at elevations larger than 30^{o} and having a subionospheric point along the line of sight within 5^{o} of the latitude and longitude of the ionosonde. The observed time delays were then corrected for satellite biases using the JPL table of corrections (Wilson and Mannucci, 1993), converted into vertical TEC (Klobuchar, 1987) and averaged to obtain hourly values.

2. EXPERIMENTAL RESULTS

Figure 1 shows the hourly values of the variability of f_oF_2 and TEC for the period 1-16 August 1992. That period is near the maximum of solar cycle 22 (monthly mean sunspot number 103). The variability is determined by subtracting the monthly average value from each hourly value and dividing by the monthly average value. The results of cross correlation analysis on the f_oF_2 and TEC depicted in Figure 1 are shown in Figure 2. A maximum cross-correlation coefficient of 0.7 occurs at zero time lag while the correlation reduces very quickly with time lag. It is thus shown that the correlation between f_oF_2 and TEC is very good. Auto-correlation results for both f_oF_2 and TEC for the same time period (Figure 3) shows that the auto-correlation is similar in character to the cross correlation function and drops to 0.5 after a time lag of 3-4 hours. This is consistent with results obtained elsewhere indicating that short-term predictions based on real-time observations can only be useful for a few hours.

It can be seen from Figure 1 that both the variations in f_oF_2 and TEC are rather noisy on an hour-to-hour basis which may be caused by measurements and data reduction errors rather than by physical phenomena. The results of smoothing the variations in TEC and f_oF_2 by a 3-hour running mean is shown in Figure 4. It can be seen that the correlation is remarkably improved (correlation coefficient of 0.8). This shows that indeed the data are noisy and that the correlation between TEC and f_oF_2 is actually better than what the raw data indicate.

The seasonal dependence of the correlation coefficient between the variability in TEC and f_oF_2 is shown in Table 1. It can be seen that the correlation coefficient is better than 0.7 in winter and summer. However, during equinox, especially in April and May 1980, the correlation drops to about 0.5. The reason for the low correlation is the large post sunset enhancements in TEC which were not seen in f_oF_2. These post sunset enhancements, observed mainly in equinox months, are attributed to electron fluxes arriving from the equatorial regions along the magnetic lines of force. They are latitude-dependent (Soicher et al., 1984) and thus did not affect the f_oF_2 observations.

The diurnal dependence of the correlation is shown in Table 2. It can be seen that higher correlation occurs during day time than night time. Between 10-18 hours local time, the correlation coefficient is about 0.7; while between 22-06 hours local time, the correlation drops to between 0.55-0.6.

TABLE 1

SEASON	MONTH	CORRELATION COEFFICIENT
Winter	Jan 80	0.74
	Feb 80	0.73
Equinox	Mar 80	0.66
	Apr 80	0.50
	May 80	0.47
Summer	Jul 81	0.73
	Jul 92	0.77
	Aug 92	0.70

TABLE 2

HOURS LT	CORRELATION COEFFICIENT
02-06	0.55
06-10	0.63
10-14	0.70
14-18	0.71
18-22	0.60
22-02	0.61

The ionosphere is known to vary substantially with magnetic activity (Goodman, 1992). To ascertain whether magnetic activity has any impact on the cross correlation of f_oF_2 and TEC, two time periods - one quiet (18-26 January 1980) and one active (14-19 February 1980) - were examined. The former with index Ap<6 is depicted in Figure 5 with maximum correlation coefficient of 0.823 and the latter with index Ap<40 is depicted in Figure 6 with maximum correlation coefficient 0.774. Thus it appears that magnetic changes do not have a marked impact on the correlation of the two ionospheric parameters.

The slab thickness τ is determined from the ratio $TEC/(f_oF_2)^2$. It is expected that the variability of τ will be smaller than the variability of either the TEC or f_oF_2 because of the good correlation between these two ionospheric parameters. Thus, global models of the slab thickness updated with real-time measurements of TEC obtained with the GPS network, might give improved values

of f_oF_2. However, the calculated variability in τ is of the same order as the corresponding variability of TEC or f_oF_2. For example, for the period 11-29 February 1980, the standard deviation of the hourly variability of τ is 16% in comparison to that of TEC which is 22%.

3. CONCLUSIONS

The high cross-correlation (>0.75) coefficient for f_oF_2 and TEC in the limited data presented in this paper raises the possibility that real time TEC measurements may be used to update f_oF_2 value determinations. The cross-correlation may even be higher if the geographic subionospheric point of the TEC measurement is closer to the geographic point of the f_oF_2 measurement, which introduces an error, in addition to the possible inherent measurement uncertainties. TEC measurements utilizing satellite emitted signals are passive in nature and do not burden the electromagnetic spectrum. In addition, the availability of the global GPS constellation to provide instantaneous time-delay, or equivalently TEC, values could provide an instantaneous updating of f_oF_2 models on a global basis as well as on a regional basis. Such capability is important for HF communication along short, medium and long range paths.

4. REFERENCES

Goodman, J. M., HF Communication Science and Technology, Van Nostrand Reinhold, New York, NY, PP631, 1992.

Klobuchar, J. A., Ionospheric Time-Delay Algorithm for Single Frequency GPS Users, IEEE Trans AES, AES-23, 325-331, 1987.

Soicher, H., Z. Houminer and A. Shuval, Total Electron content in the Middle East, Radio Science, 17, 1623-1631, 1982.

Soicher, H., J. A. Klobuchar and P. H. Doherty, Spatial Variability of Total Electron Content in the Eastern Mediterranean Region, Radio Science, 19, 757-764, 1984.

Wilson, B. D. and A. J. Mannucci, Instrumental Biases in Ionospheric Measurements Derived from GPS Data, Proceedings of the Institute of Navigation GPS-93, Salt Lake City, Utah, September 1993.

5. FIGURE CAPTIONS

1. Hourly values of the variability of f_oF_2 (at Cyprus) and TEC (at Israel) for the time period 1-16 August 1992.

2. Crosscorrelation function for the f_oF_2 and TEC values of Figure 1.

3. Autocorrelation functions for the f_oF_2 and TEC values of Figure 1.

4. Smoothed hourly values of the variability values of Figure 1.

5. The variability (in percent) of f_oF_2 and TEC for the geomagnetically quiet period of 18-26 January 1980.

6. The variability (in percent) of f_oF_2 and TEC for the geomagnetically active period of 14-19 February 1980.

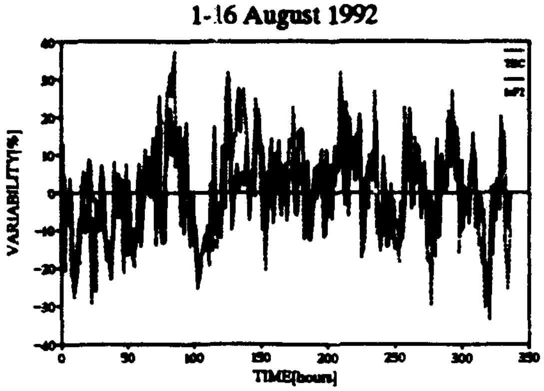


Figure 1

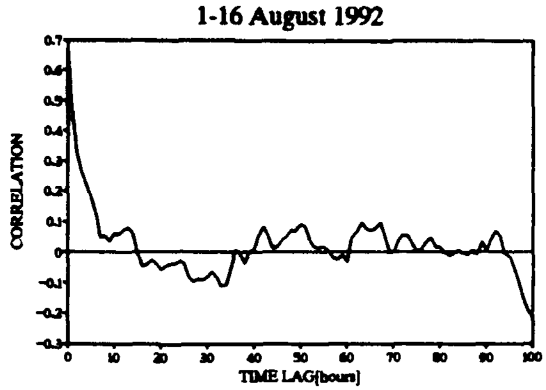


Figure 2

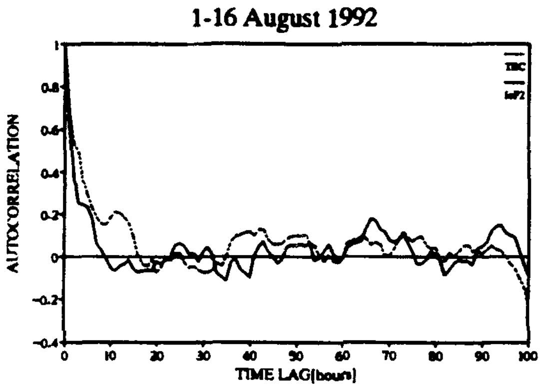


Figure 3

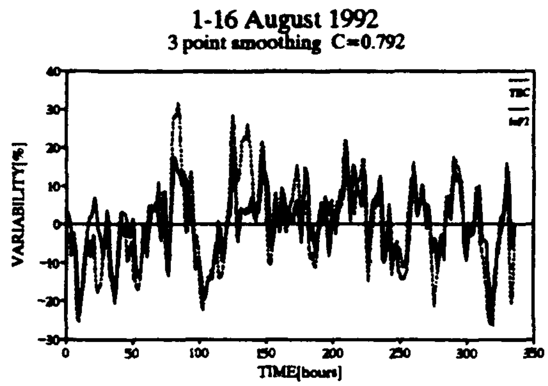


Figure 4

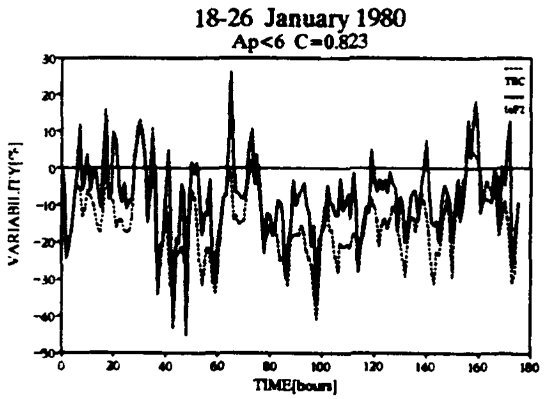


Figure 5

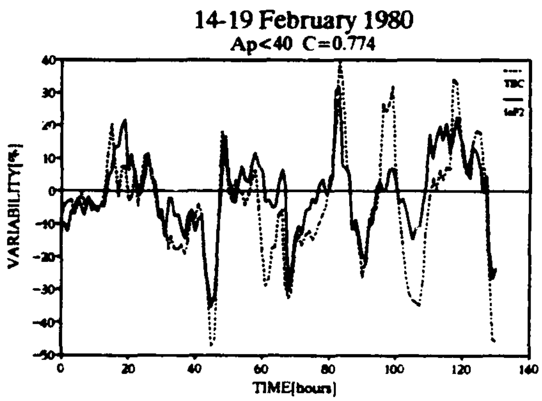


Figure 6

APPENDIX B

Experimental results for the period January - May 1980, July 1981 and June - August 1992.

The following are the figure captions:

Fig B-1	Hourly values of the variability of foF2 and TEC for the period 8-31 January 1980.
Fig B-2	Cross-correlation function between foF2 and TEC for the period 8-31 January 1980.
Fig B-3	Auto-correlation functions for foF2 and TEC for the period 8-31 January 1980.
Fig B-4	Hourly values of the variability of τ for the period 8-31 January 1980.
Fig B-5	Hourly values of the variability of foF2 and TEC for the period 11-29 February 1980.
Fig B-6	Cross-correlation function between foF2 and TEC for the period 11-29 February 1980.
Fig B-7	Auto-correlation functions for foF2 and TEC for the period 11-29 February 1980.
Fig B-8	Hourly values of the variability of τ for the period 11-29 February 1980.
Fig B-9	Hourly values of the variability of foF2 and TEC for the period 1-31 March 1980.
Fig B-10	Cross-correlation function between foF2 and TEC for the period 1-31 March 1980.
Fig B-11	Auto-correlation functions for foF2 and TEC for the period 1-31 March 1980.
Fig B-12	Hourly values of the variability of τ for the = period 1-31 March 1980.
Fig B-13	Hourly values of the variability of foF2 and TEC for the period 1-30 April 1980.
Fig B-14	Cross-correlation function between foF2 and TEC for the period 1-30 April 1980.
Fig B-15	Auto-correlation functions for foF2 and TEC for the period 1-30 April 1980.

8-31 January 1980
C=0.738

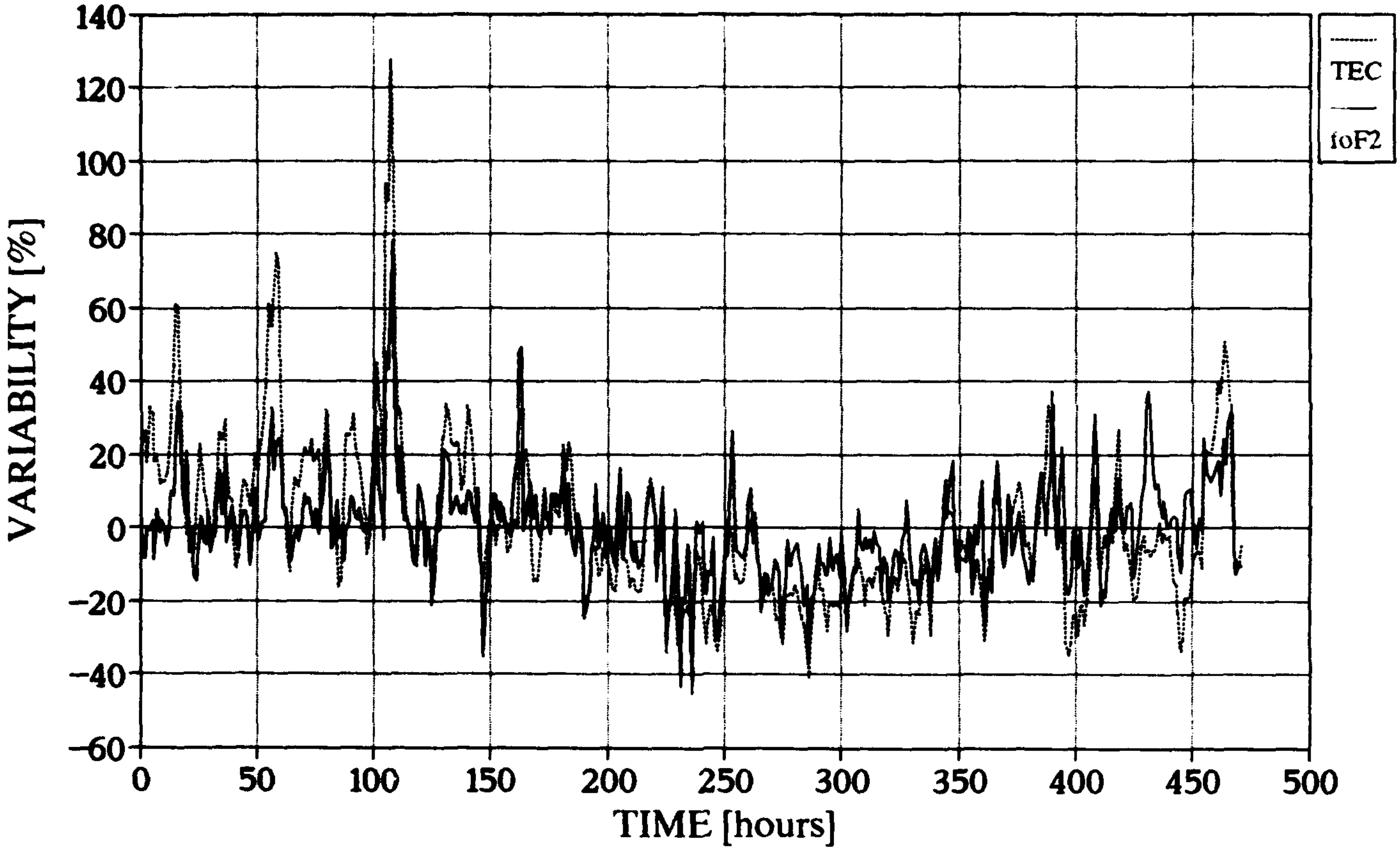


Fig B-1

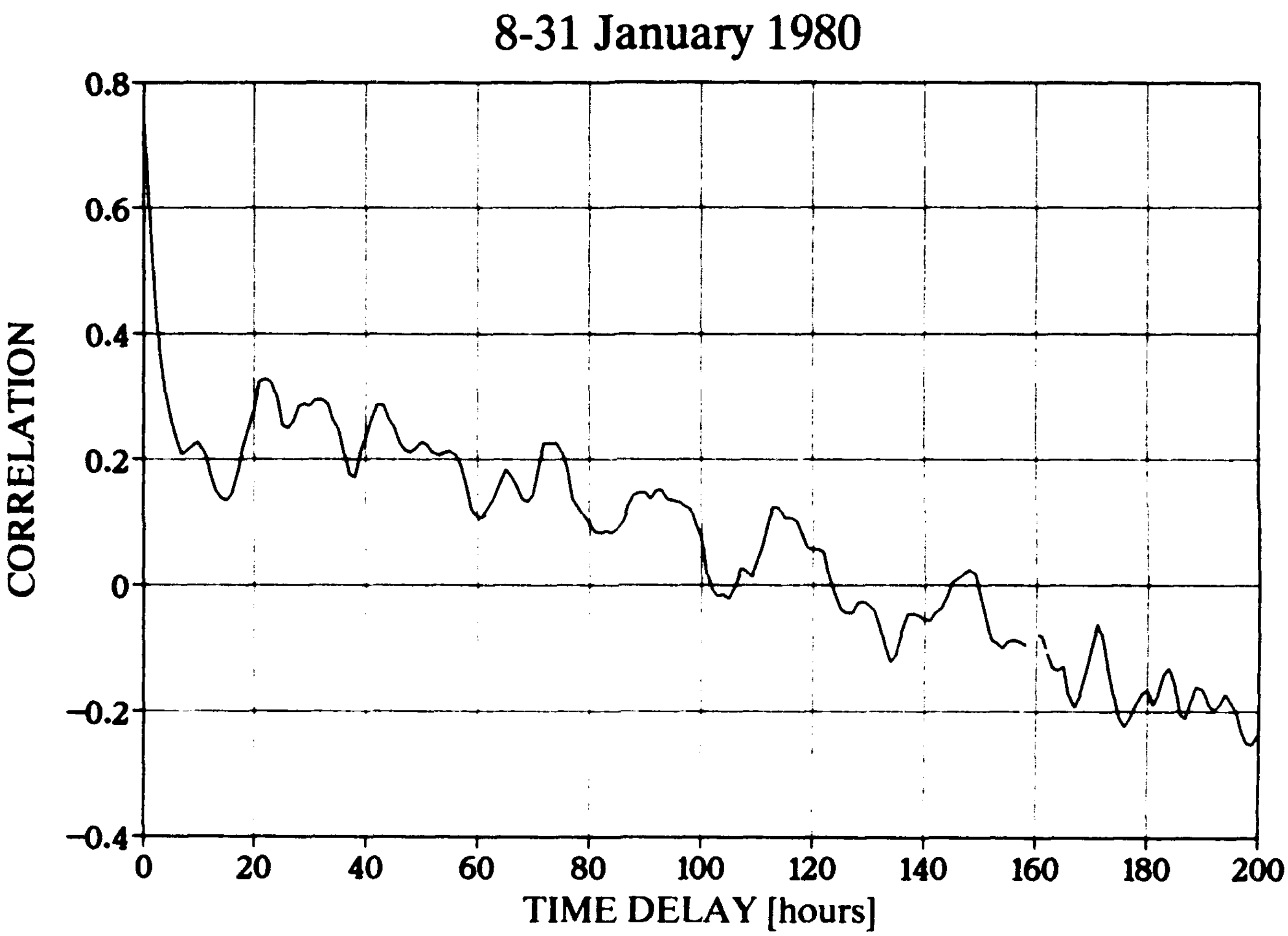

8-31 January 1980
CORRELATION
0.8
0.6
0.4
0.2
0
−0.2
−0.4
0
20
40
60
80
100
120
140
160
180
200
TIME DELAY [hours]

Fig B-2

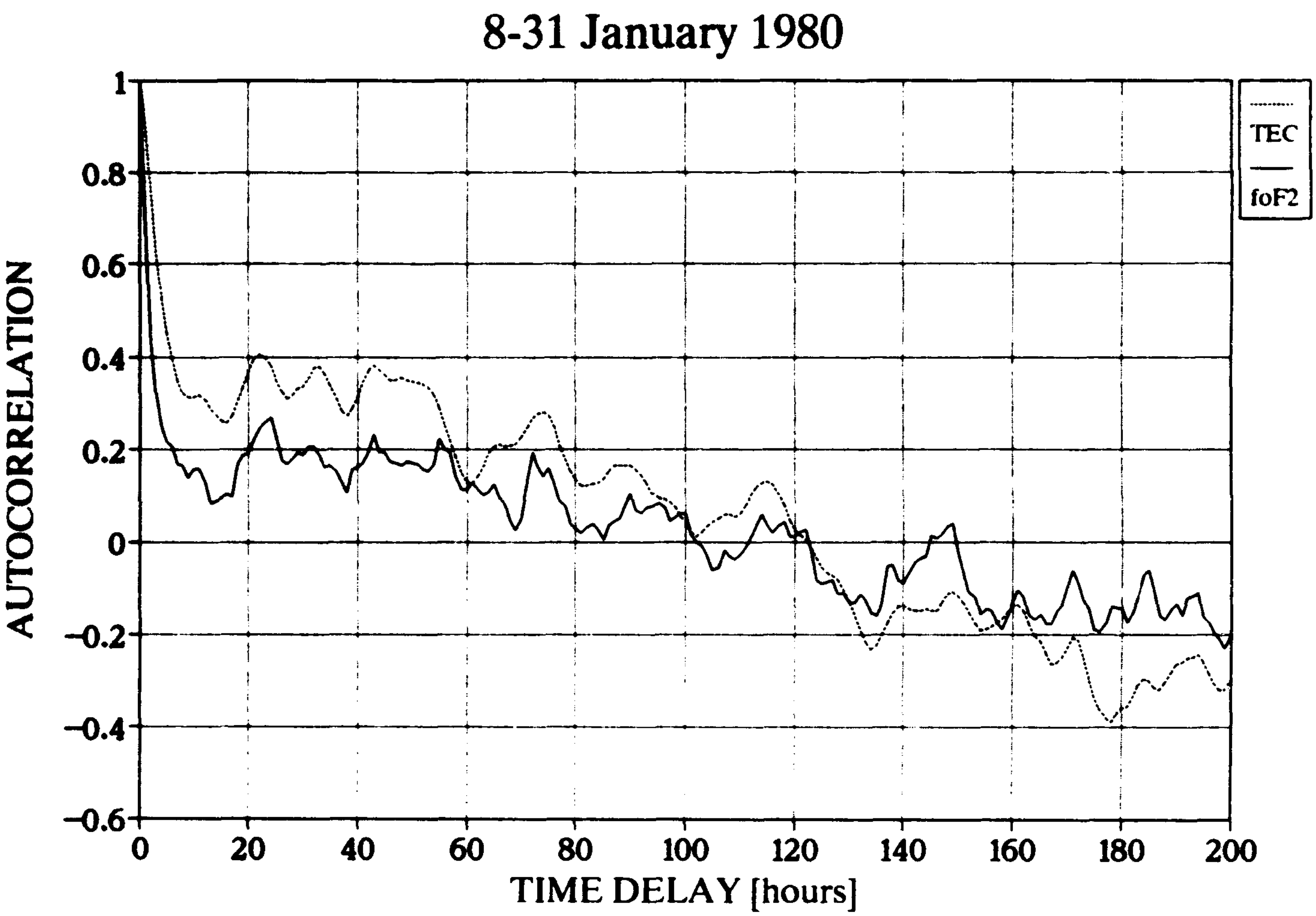
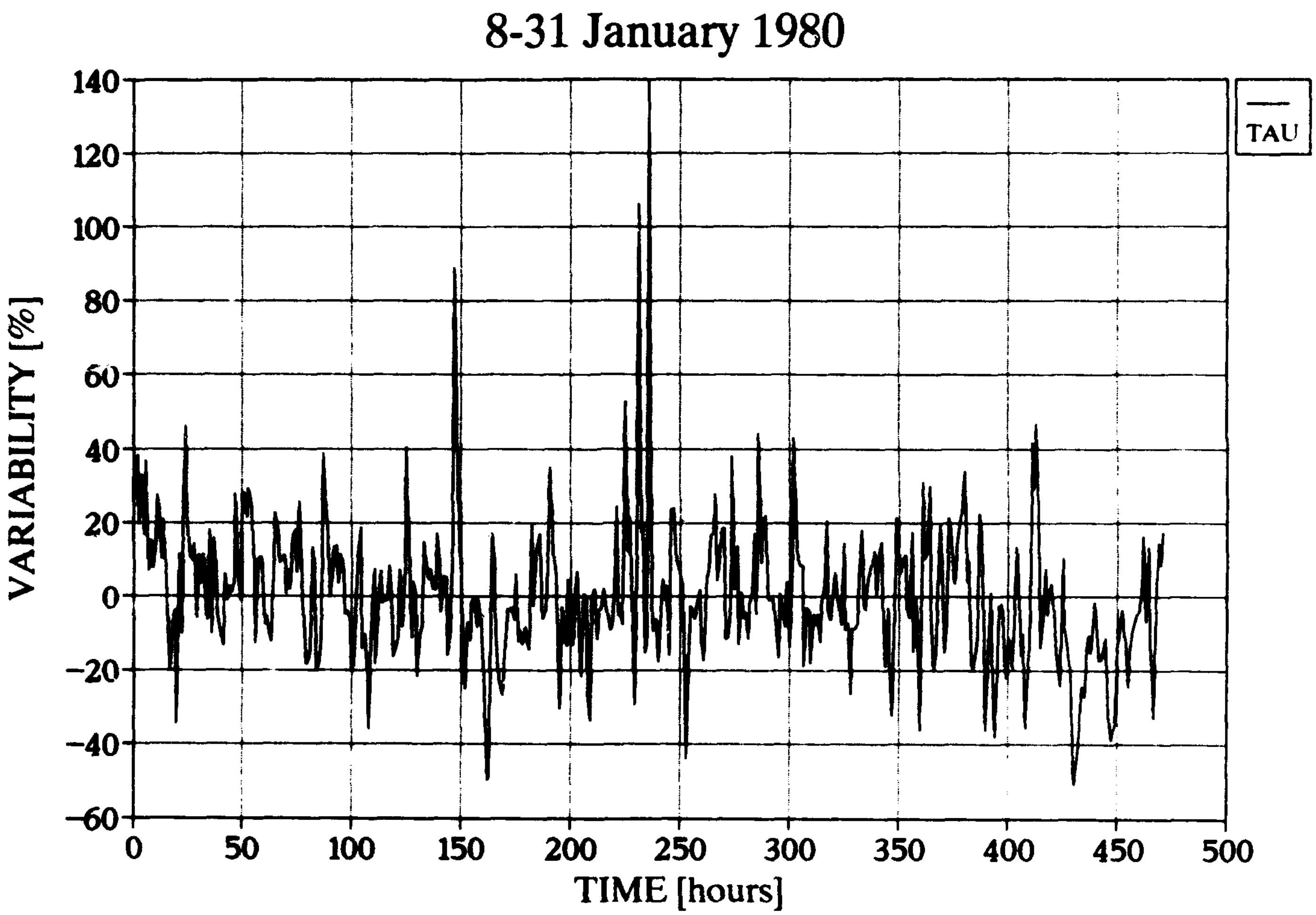
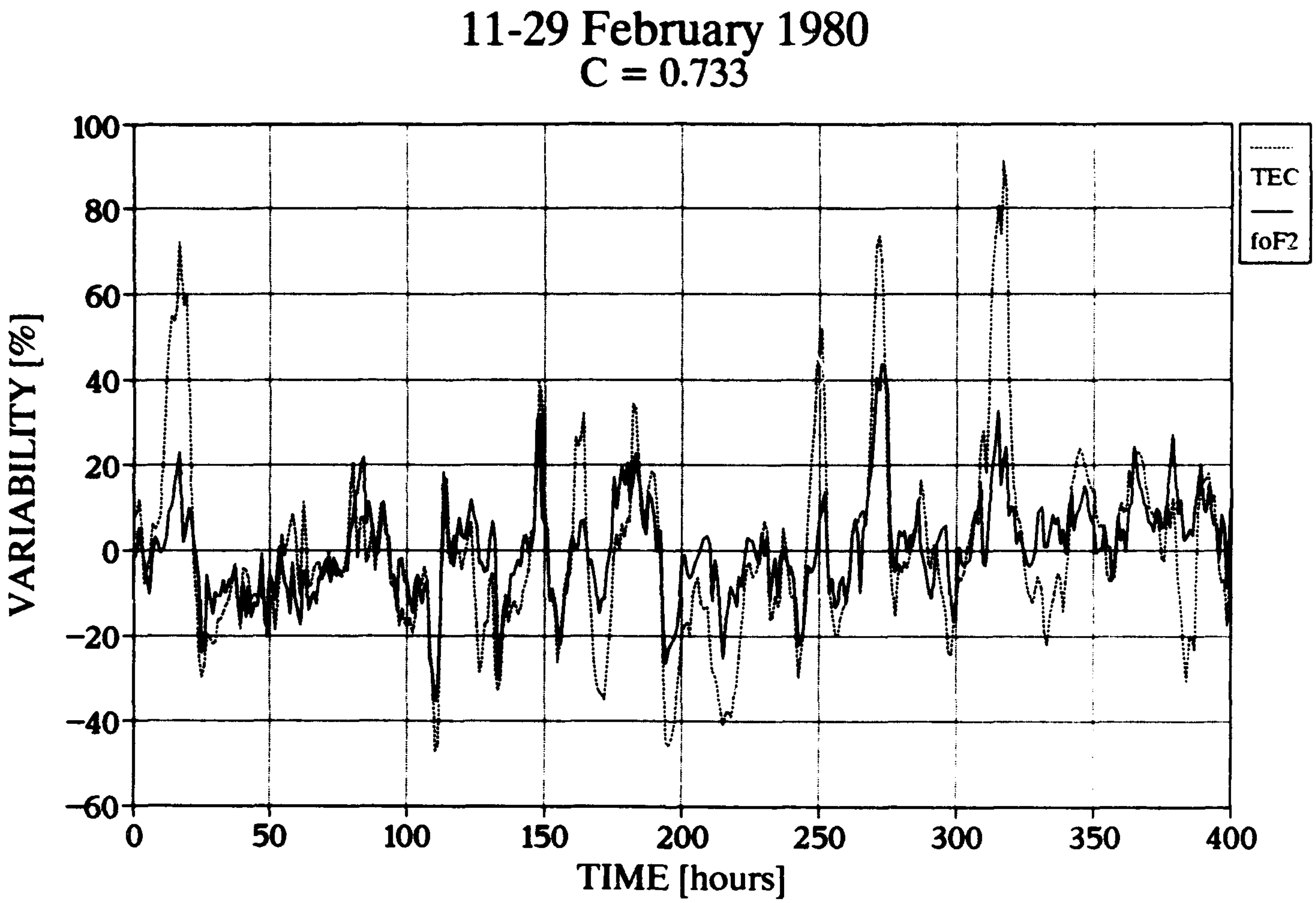

8-31 January 1980
AUTOCORRELATION
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
0
20
40
60
80
100
120
140
160
180
200
TIME DELAY [hours]
TEC
foF2

Fig B-3



8-31 January 1980
VARIABILITY [%]
TIME [hours]
TAU
140
120
100
80
60
40
20
0
−20
−40
−60
0
50
100
150
200
250
300
350
400
450
500

Fig B-4


11-29 February 1980
C = 0.733
VARIABILITY [%]
100
80
60
40
20
0
−20
−40
−60
0
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150
200
250
300
350
400
TIME [hours]
TEC
foF2

Fig B-5

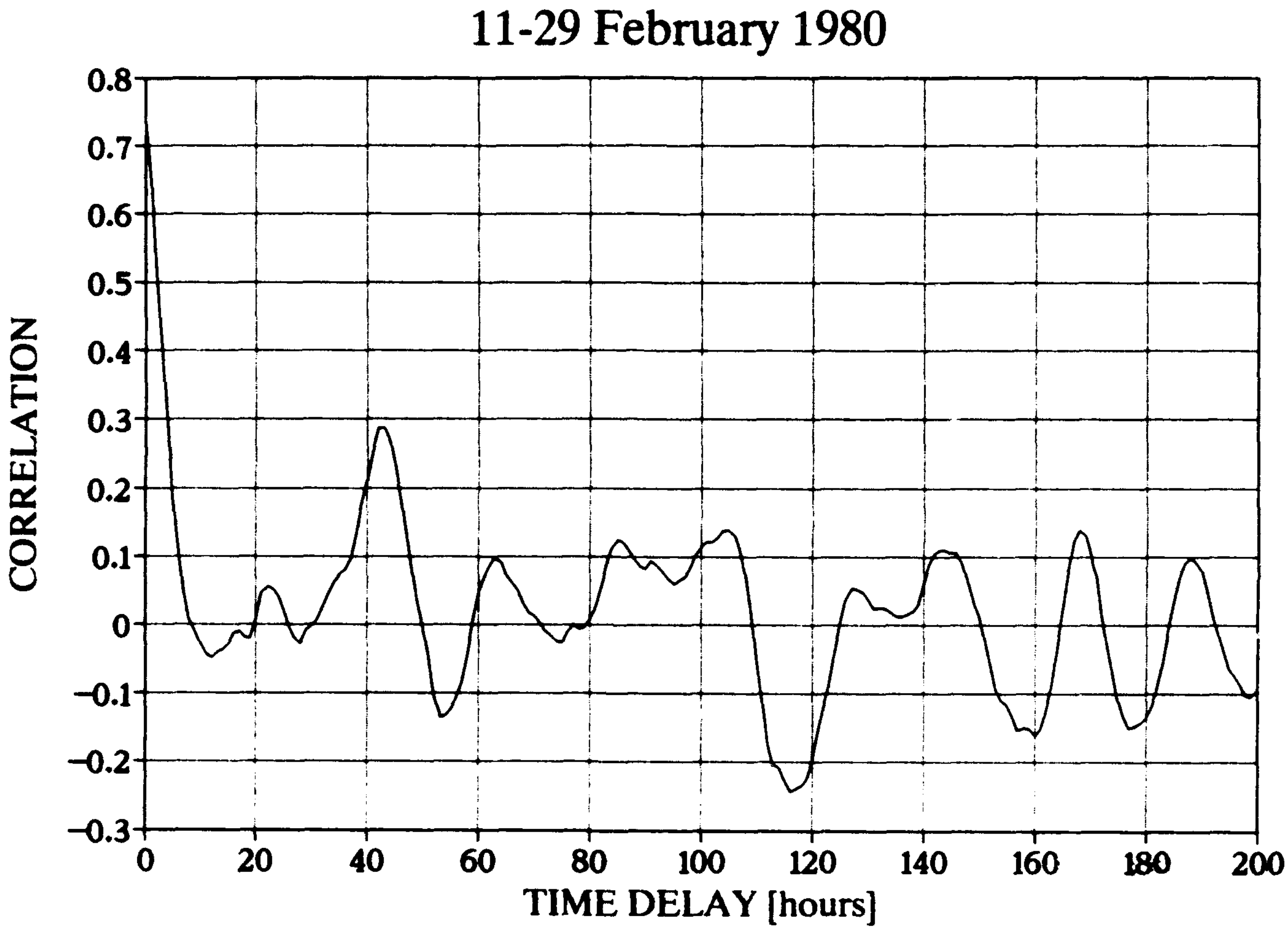

11-29 February 1980
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
CORRELATION
0
20
40
60
80
100
120
140
160
180
200
TIME DELAY [hours]

Fig B-6

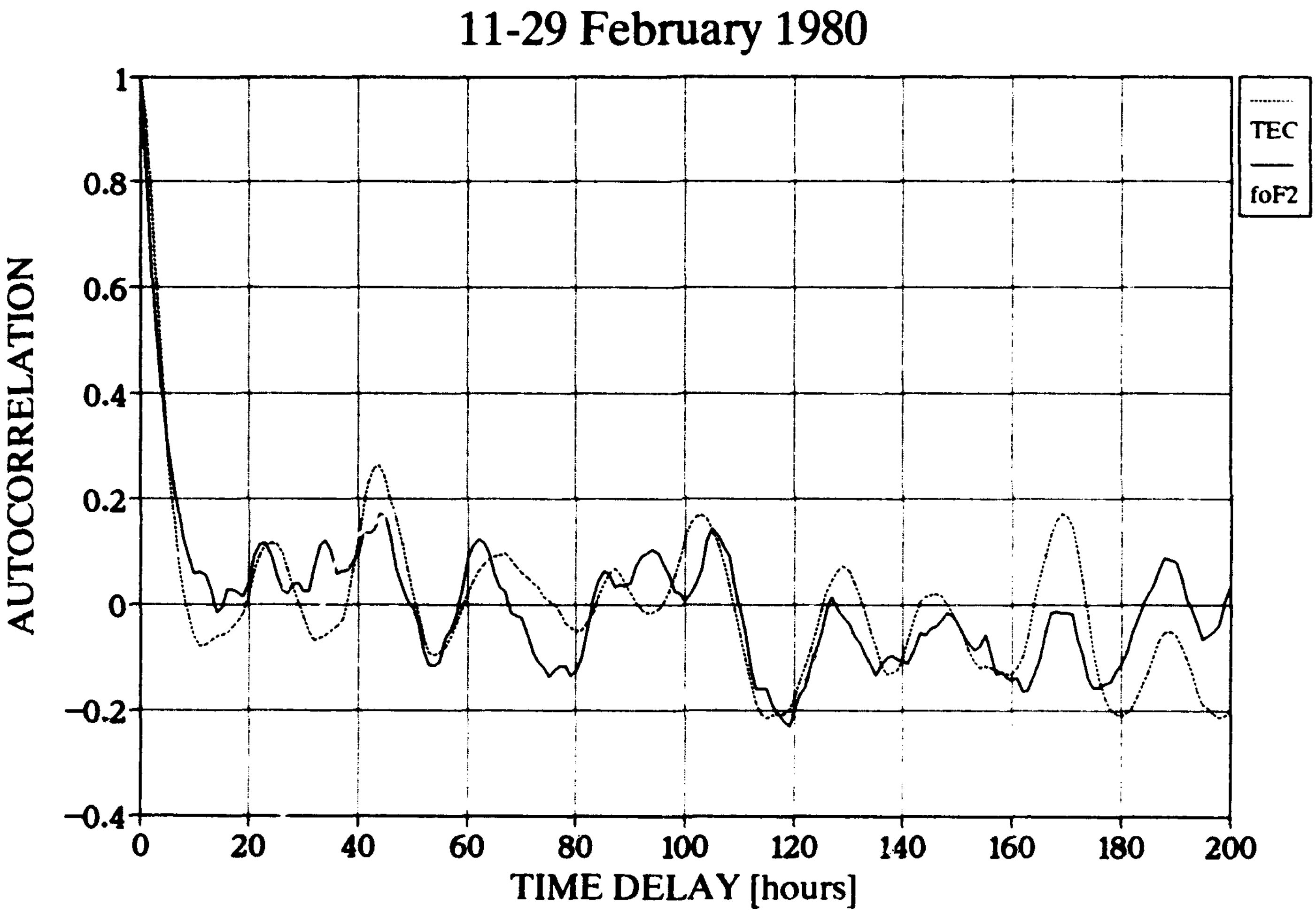

11-29 February 1980
AUTOCORRELATION
TIME DELAY [hours]
TEC
foF2
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
0
20
40
60
80
100
120
140
160
180
200

Fig B-7

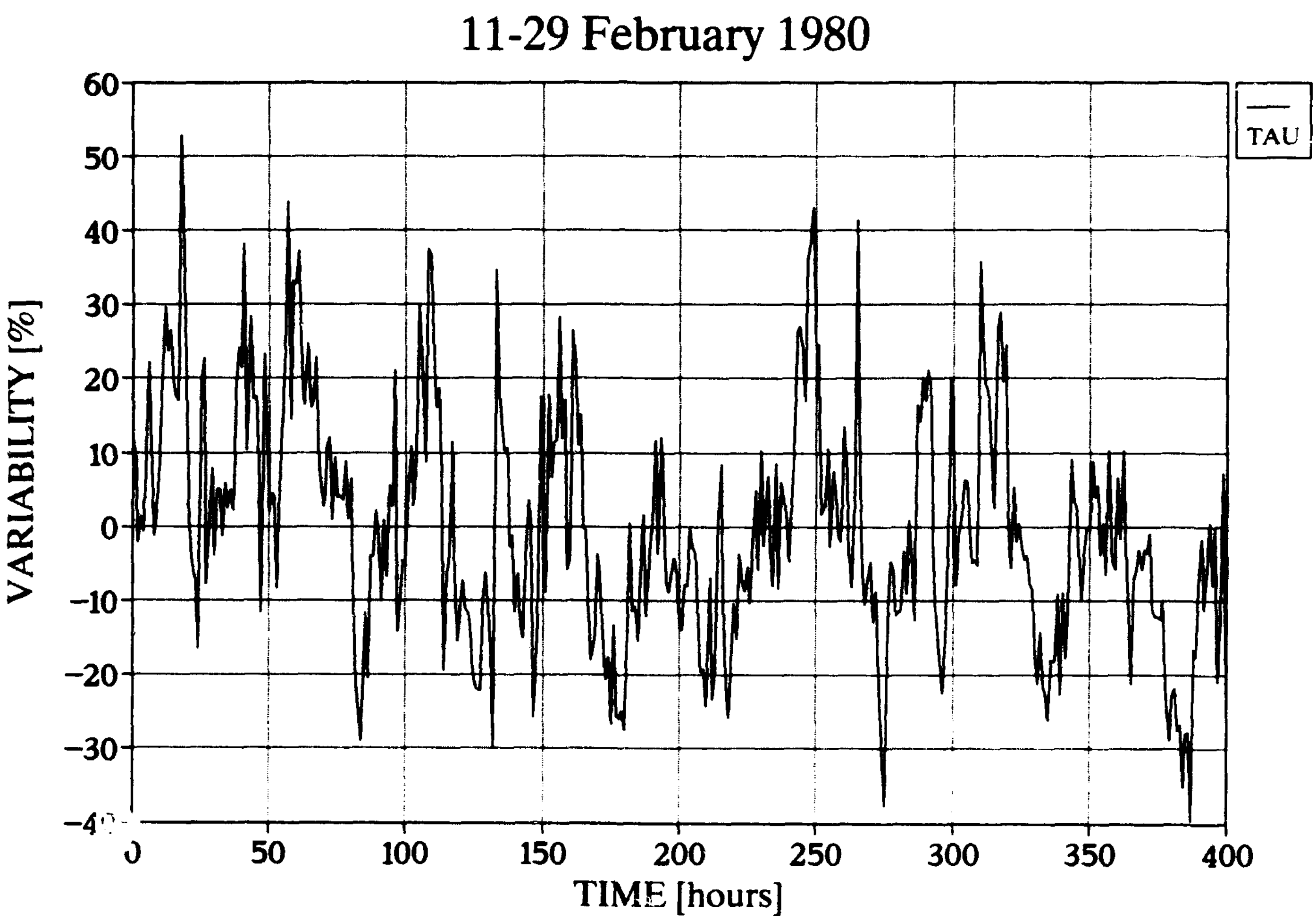

11-29 February 1980
60
50
40
30
20
10
0
−10
−20
−30
−40
0
50
100
150
200
250
300
350
400
VARIABILITY [%]
TIME [hours]
TAU

Fig B-8

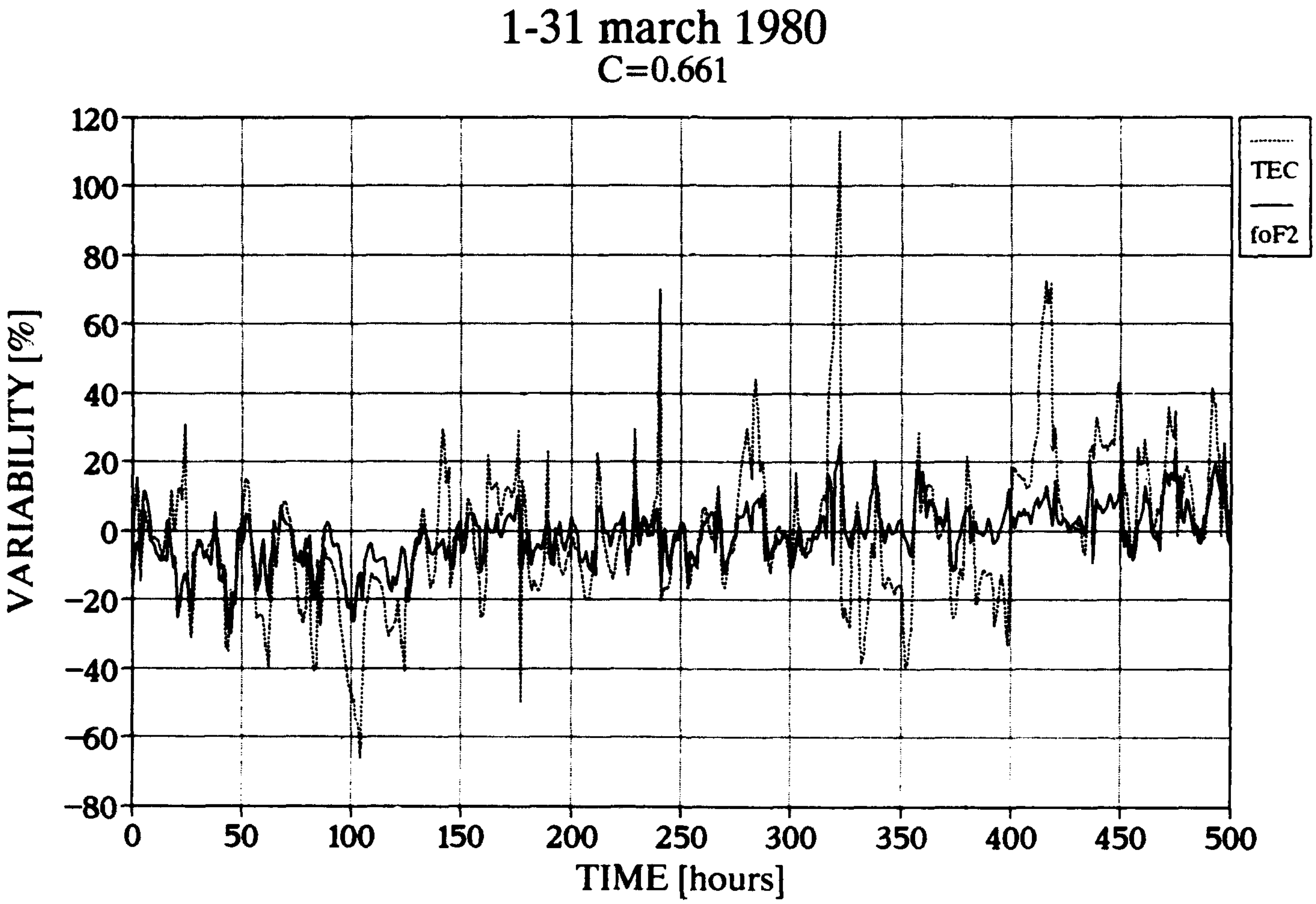
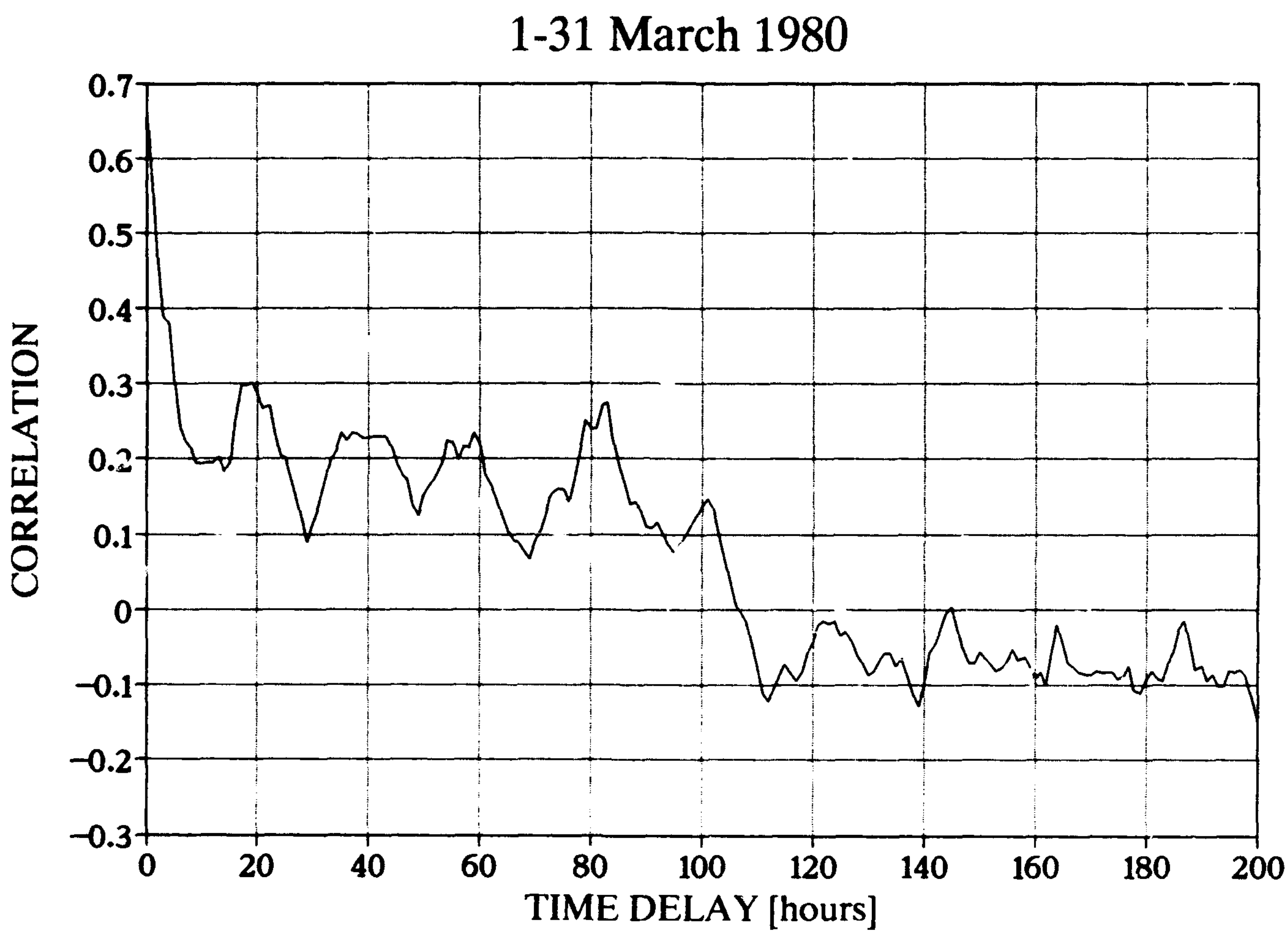

1-31 march 1980
C=0.661
120
100
80
60
40
20
0
−20
−40
−60
−80
VARIABILITY [%]
0
50
100
150
200
250
300
350
400
450
500
TIME [hours]
TEC
foF2

Fig B-9


1-31 March 1980
CORRELATION
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
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20
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200
TIME DELAY [hours]

Fig B-10

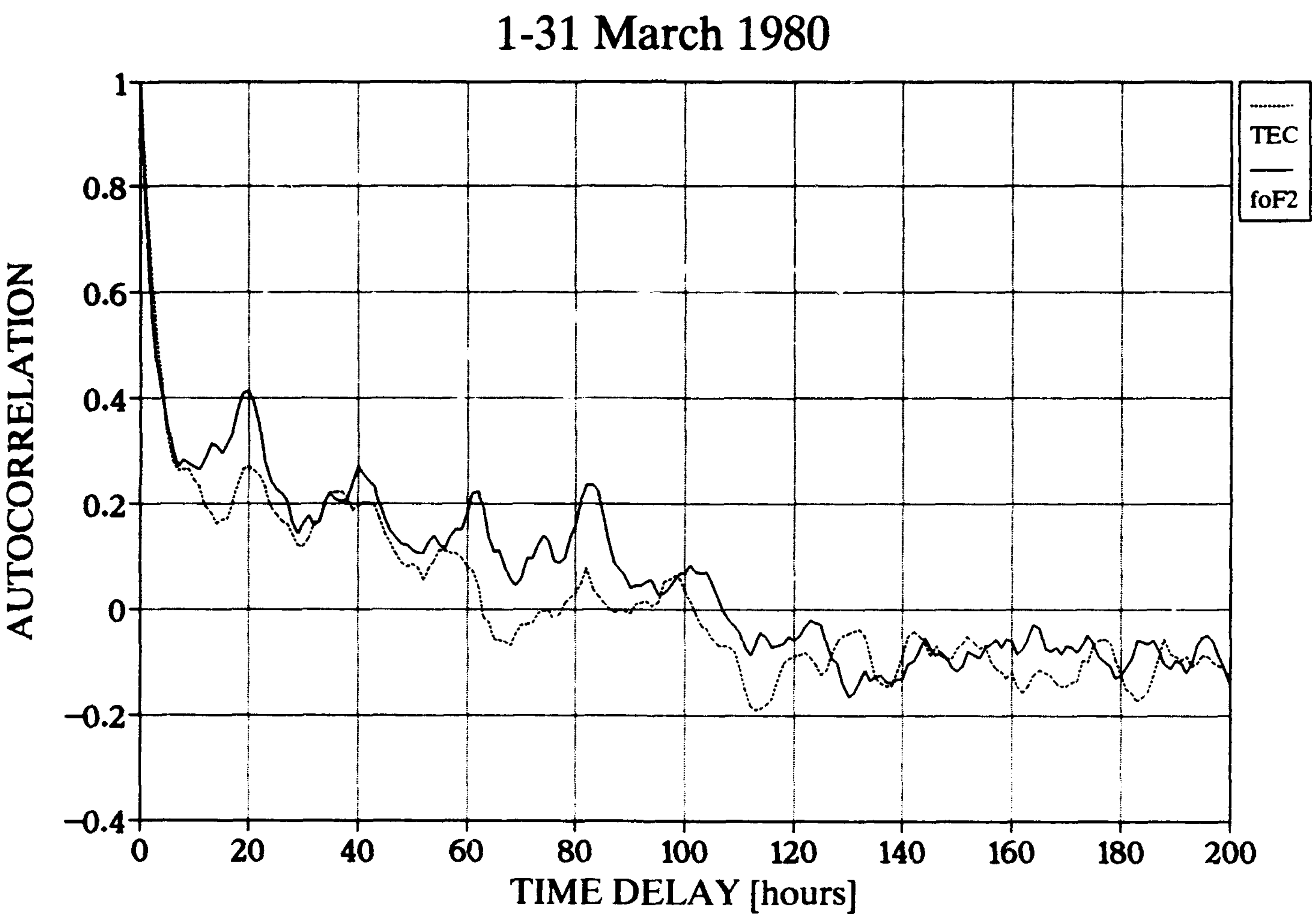

1-31 March 1980
TEC
foF2
AUTOCORRELATION
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
0
20
40
60
80
100
120
140
160
180
200
TIME DELAY [hours]

Fig B-11

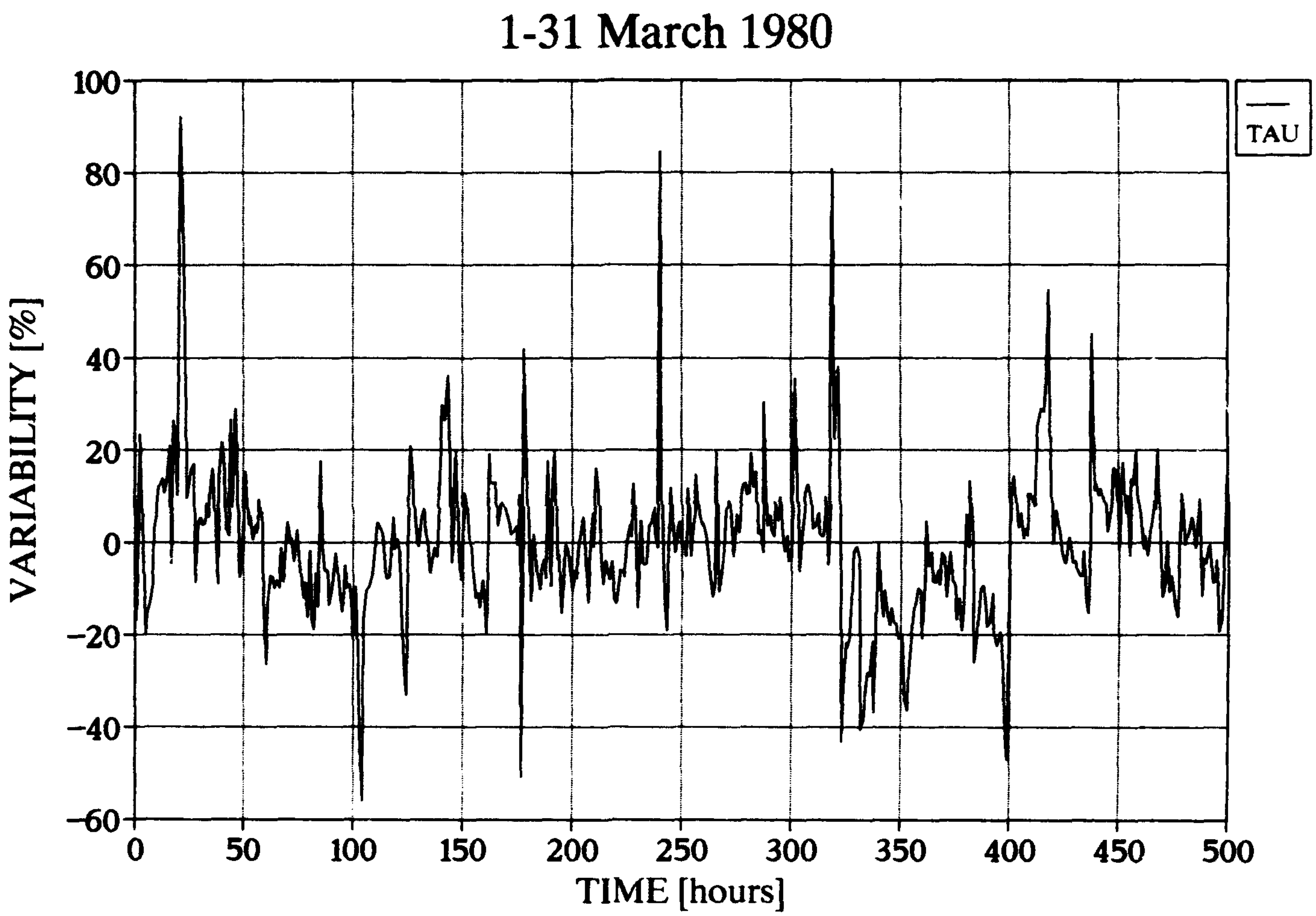
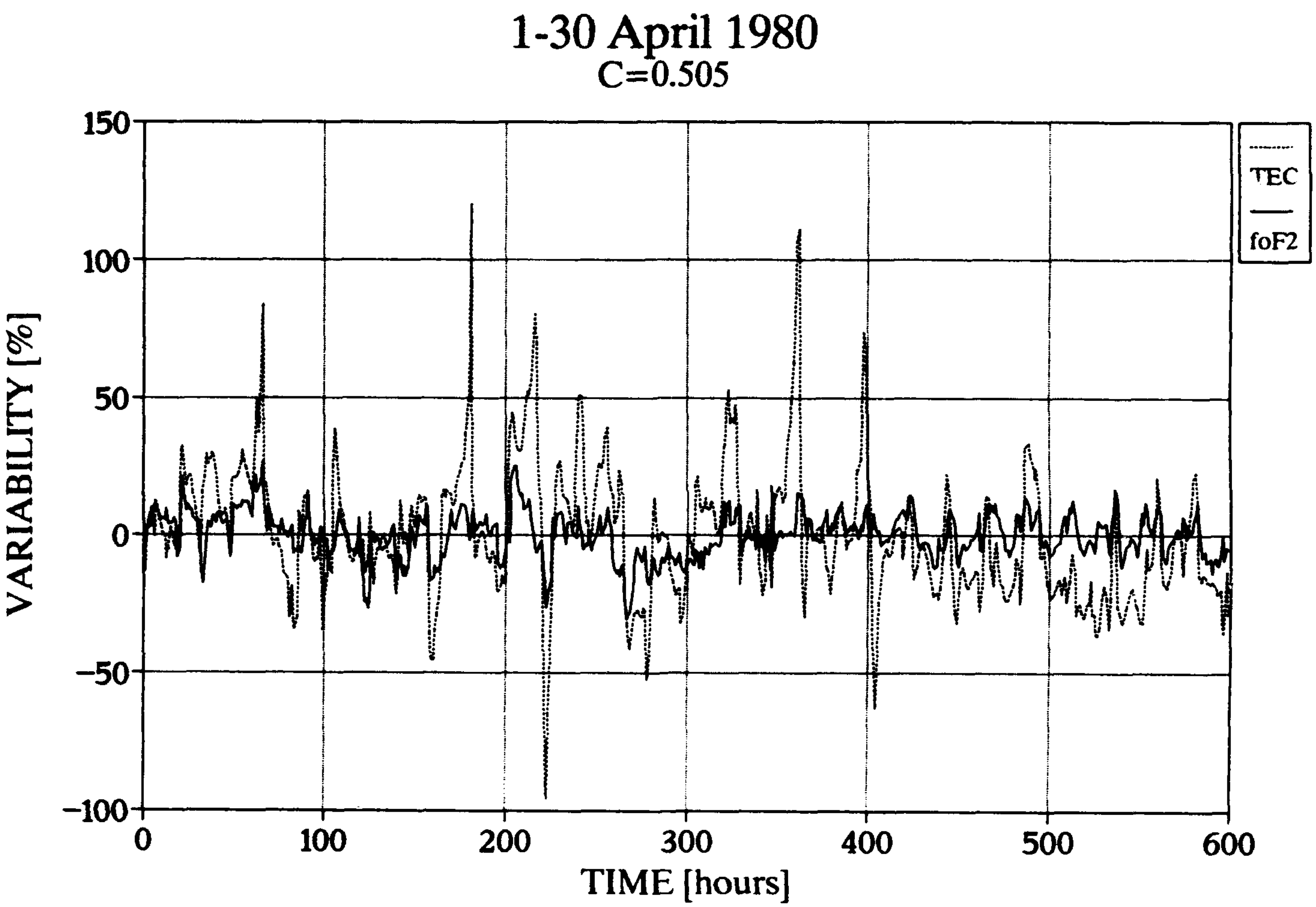

1-31 March 1980
100
80
60
40
20
0
−20
−40
−60
VARIABILITY [%]
0
50
100
150
200
250
300
350
400
450
500
TIME [hours]
TAU

Fig B-12


1-30 April 1980
C=0.505
VARIABILITY [%]
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100
50
0
−50
−100
0
100
200
300
400
500
600
TIME [hours]
TEC
foF2

Fig B-13

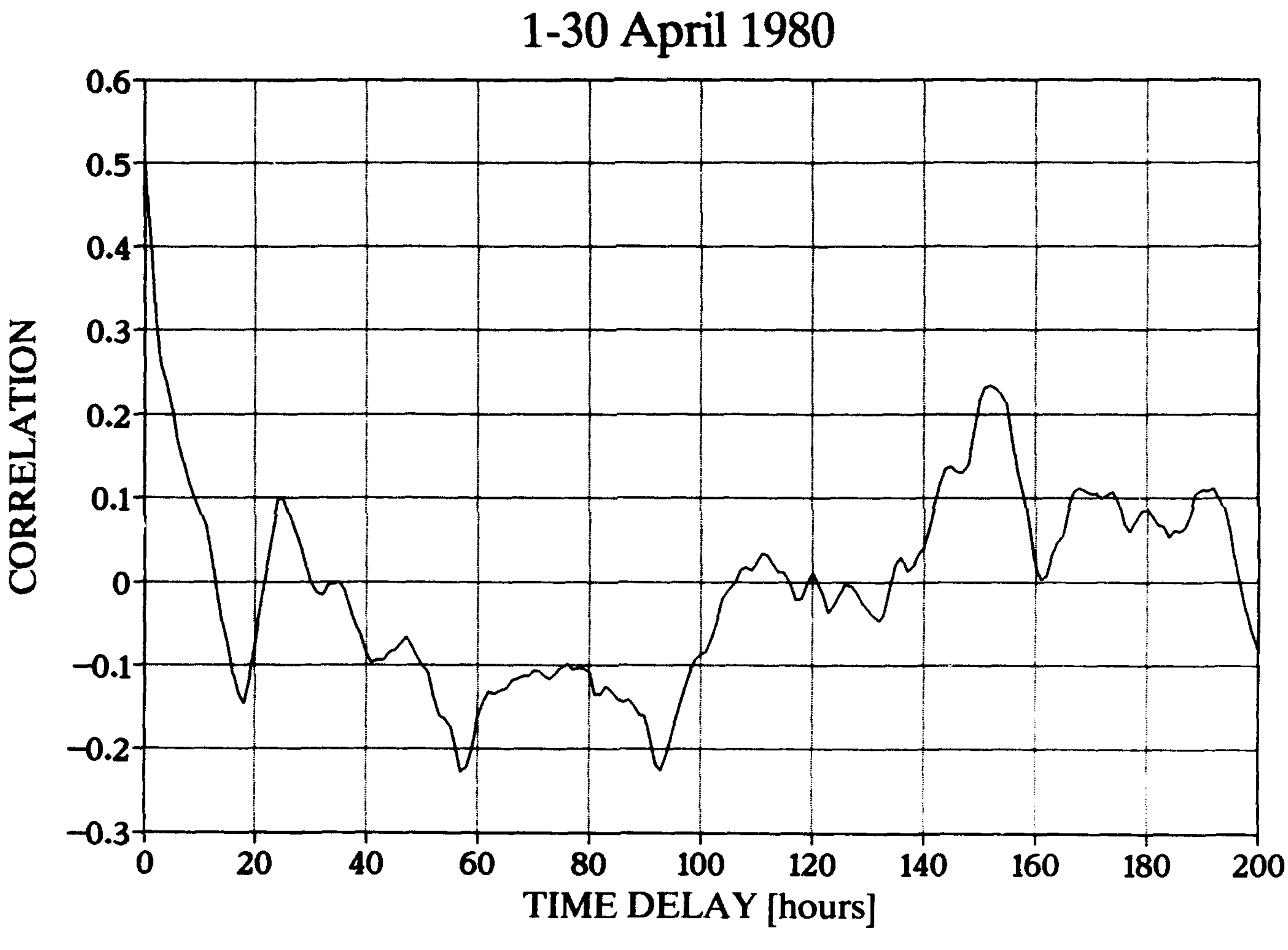

1-30 April 1980
CORRELATION
0.6
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
0
20
40
60
80
100
120
140
160
180
200
TIME DELAY [hours]

Fig B-14

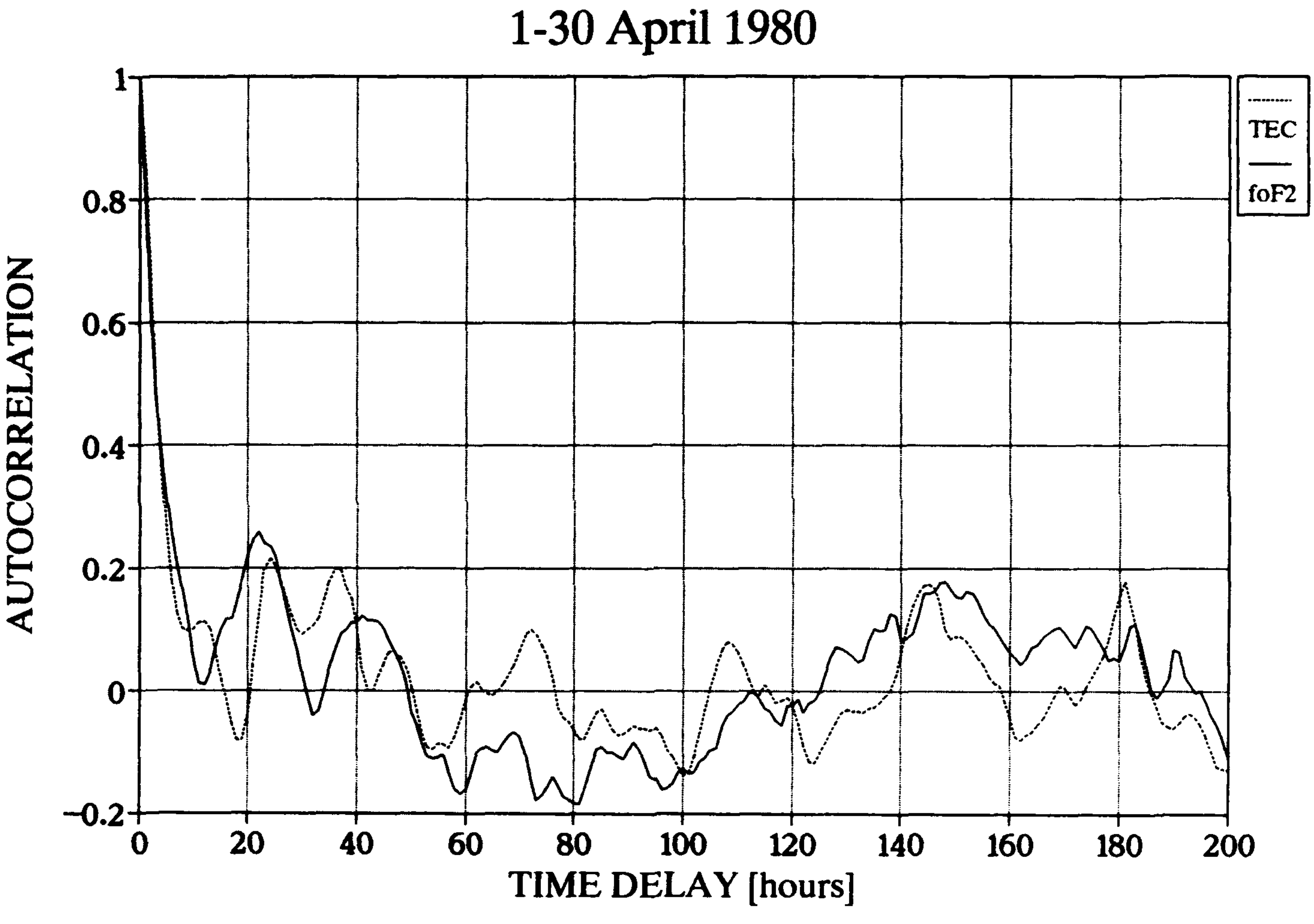

1-30 April 1980
AUTOCORRELATION
TIME DELAY [hours]
TEC
foF2
1
0.8
0.6
0.4
0.2
0
-0.2
0
20
40
60
80
100
120
140
160
180
200

Fig B-15

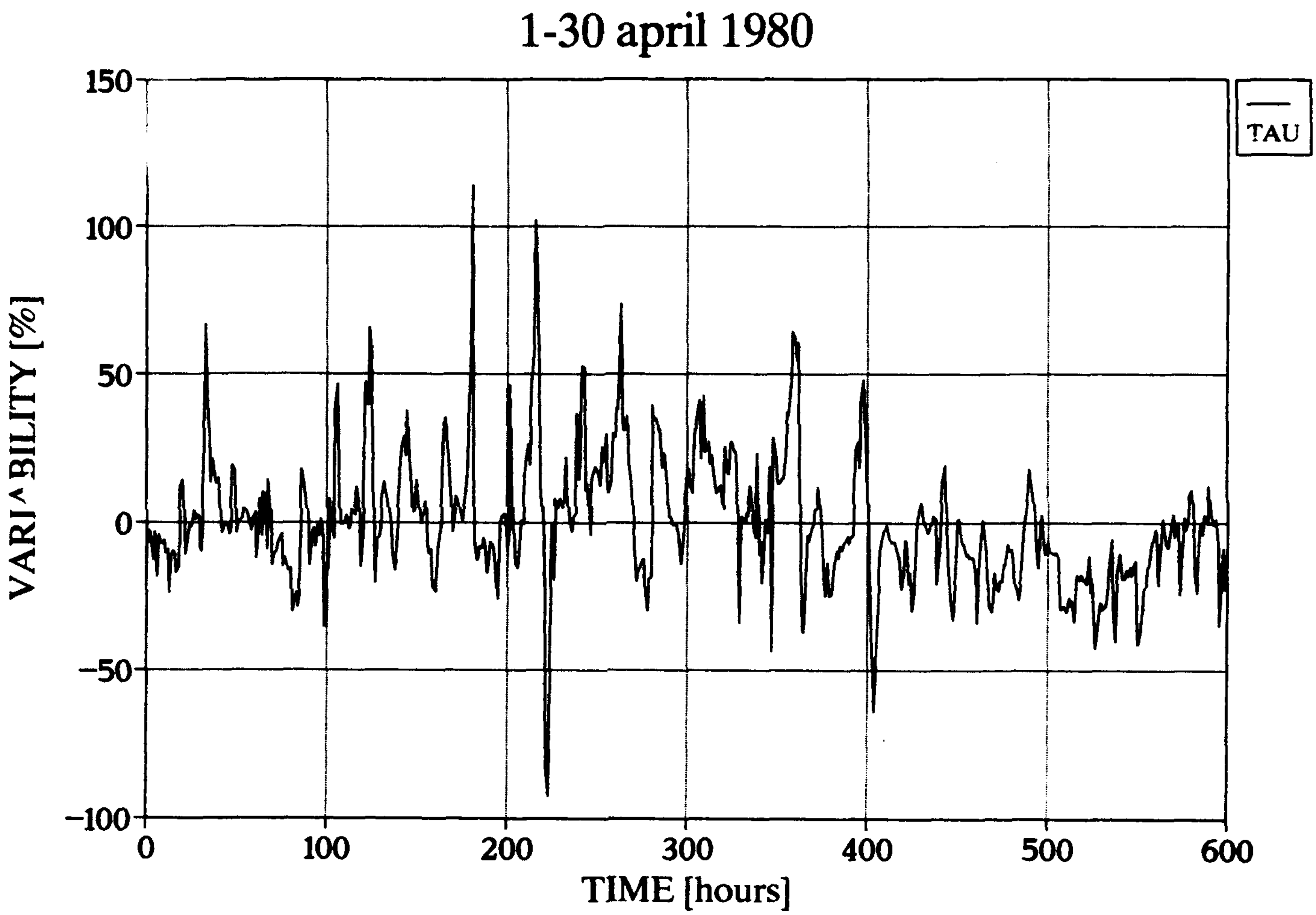

1-30 april 1980
150
100
50
0
-50
-100
0
100
200
300
400
500
600
TIME [hours]
VARIABILITY [%]
TAU

Fig B-16

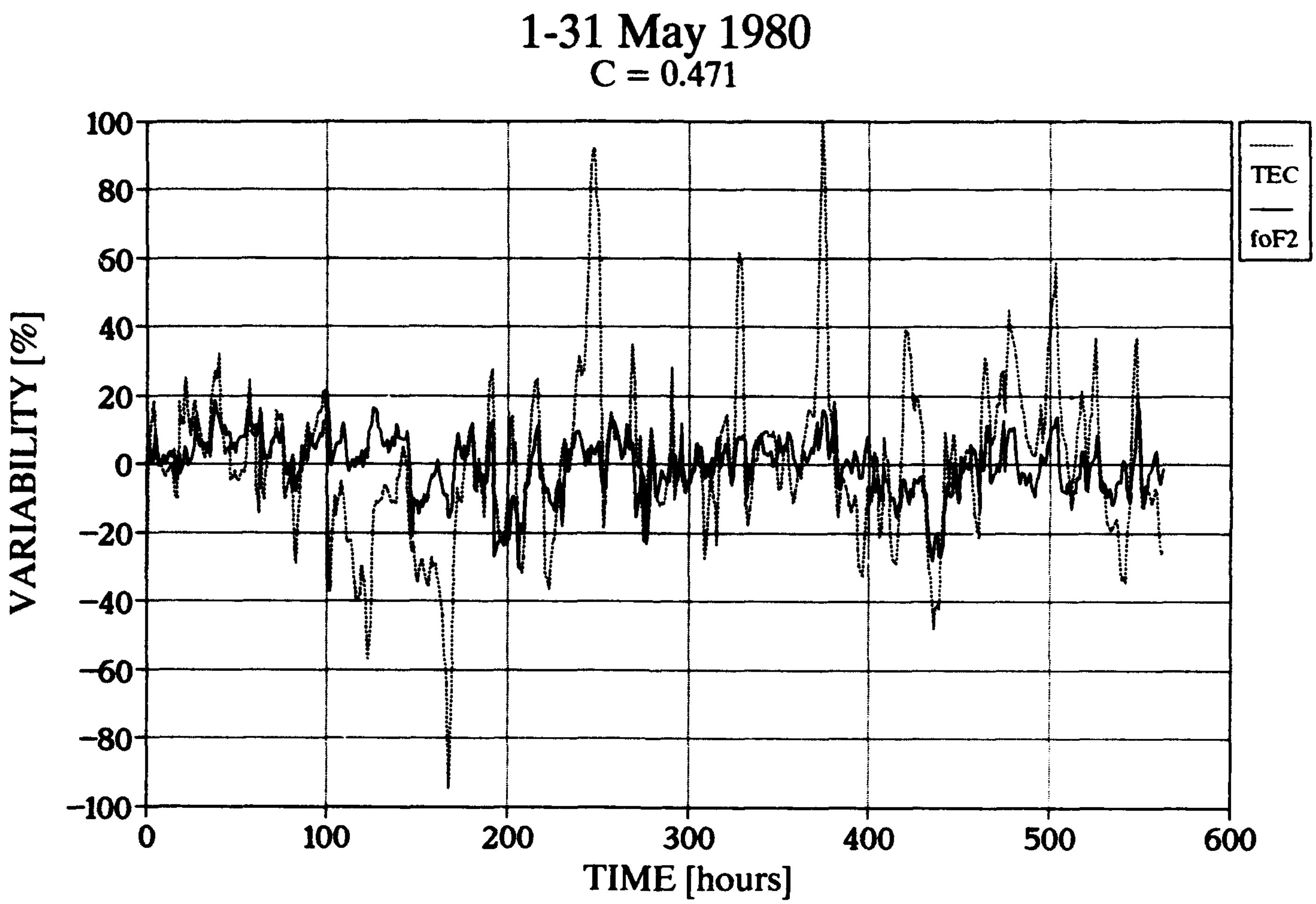

1-31 May 1980
C = 0.471
100
80
60
40
20
0
−20
−40
−60
−80
−100
0
100
200
300
400
500
600
VARIABILITY [%]
TIME [hours]
TEC
foF2

Fig B-17

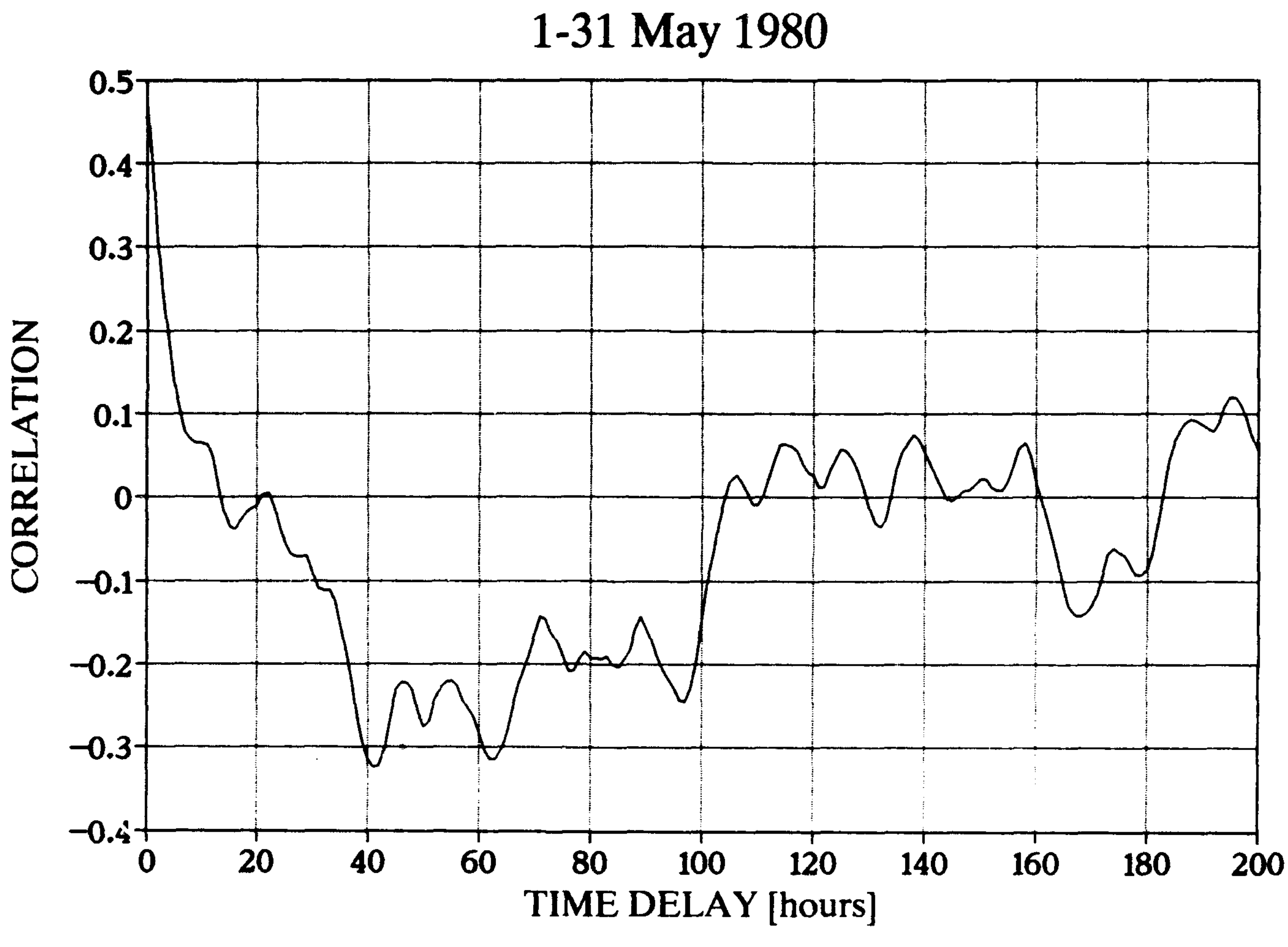

1-31 May 1980
CORRELATION
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
0
20
40
60
80
100
120
140
160
180
200
TIME DELAY [hours]

Fig B-18

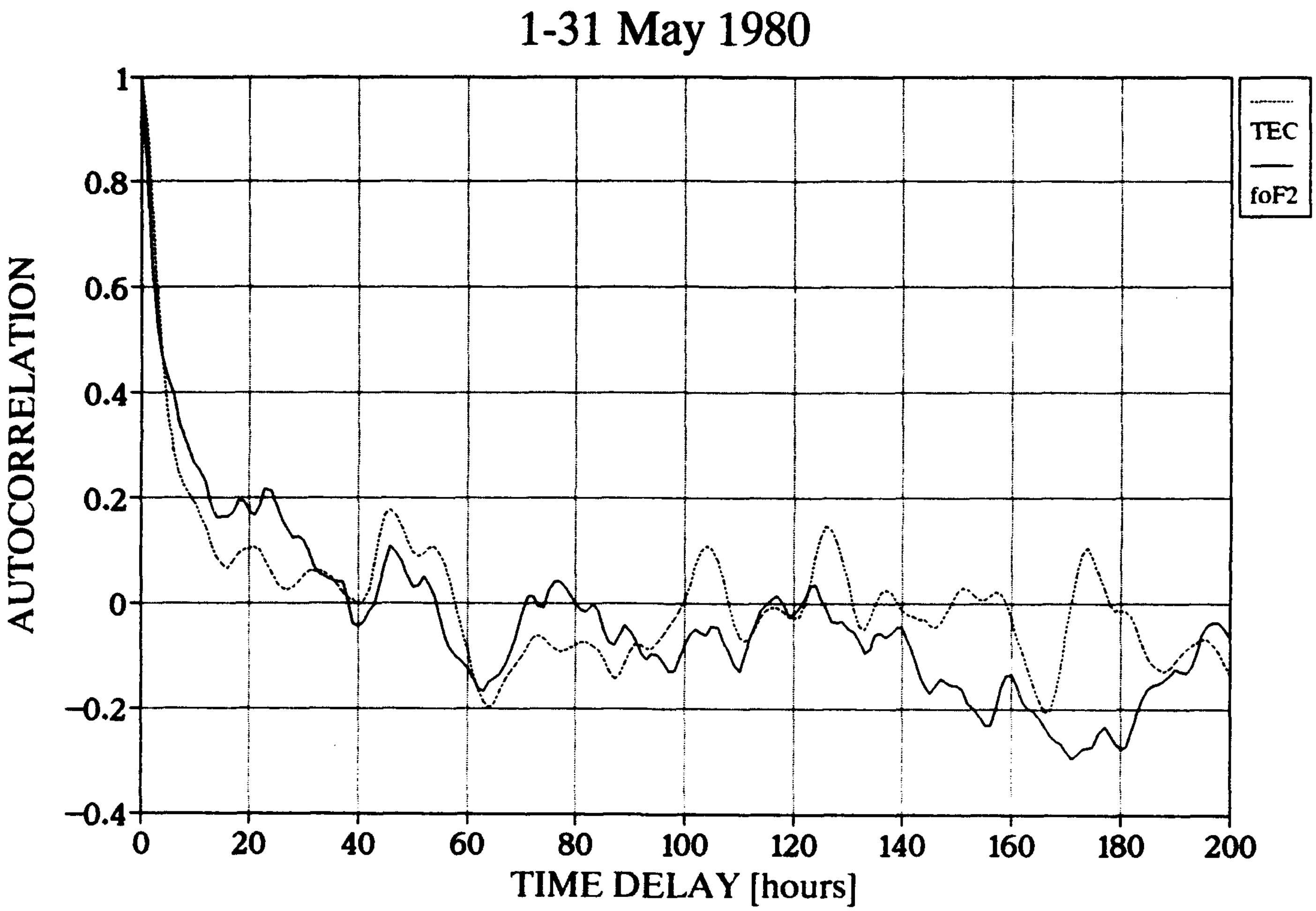

1-31 May 1980
AUTOCORRELATION
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
0
20
40
60
80
100
120
140
160
180
200
TIME DELAY [hours]
TEC
foF2

Fig B-19

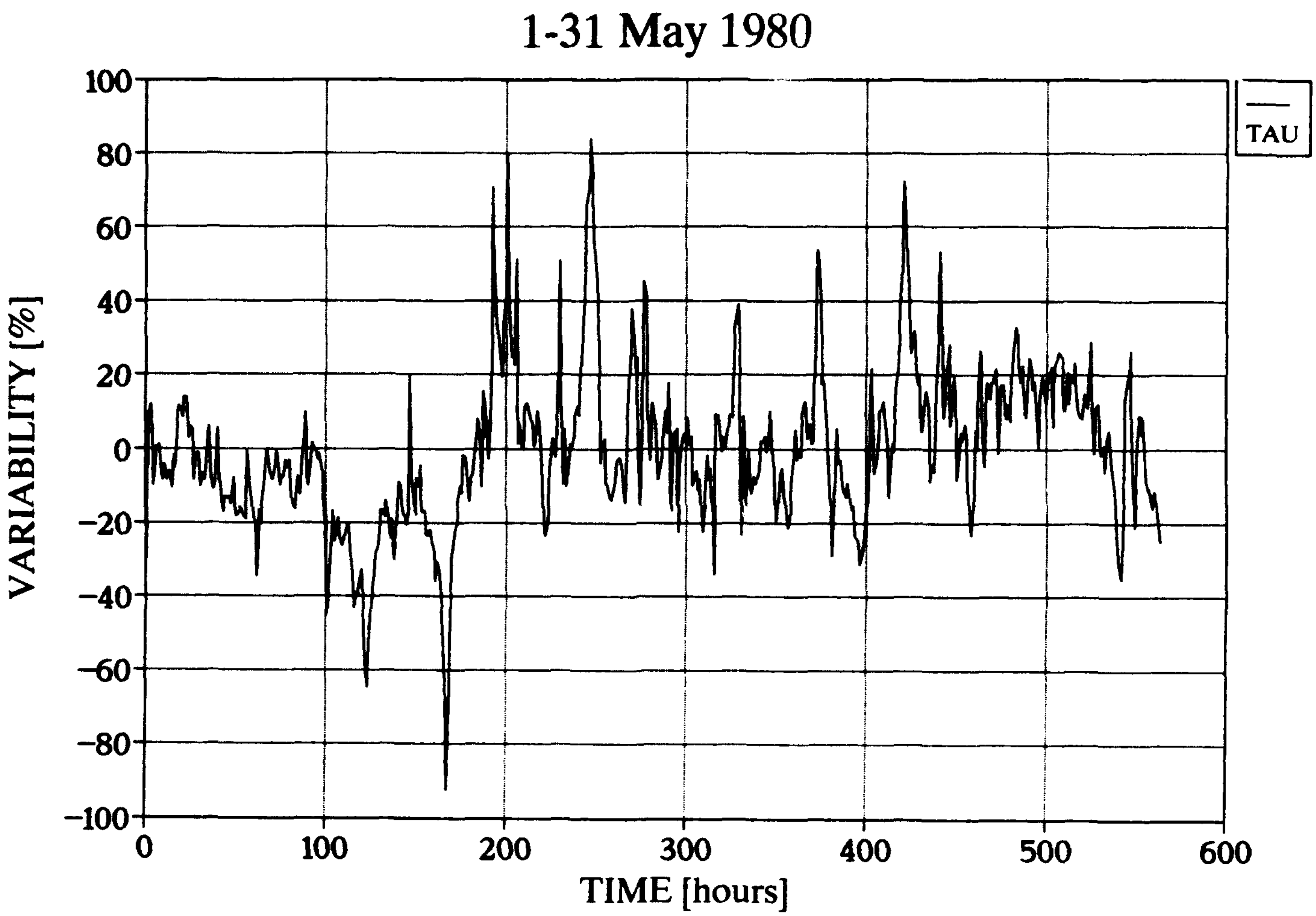
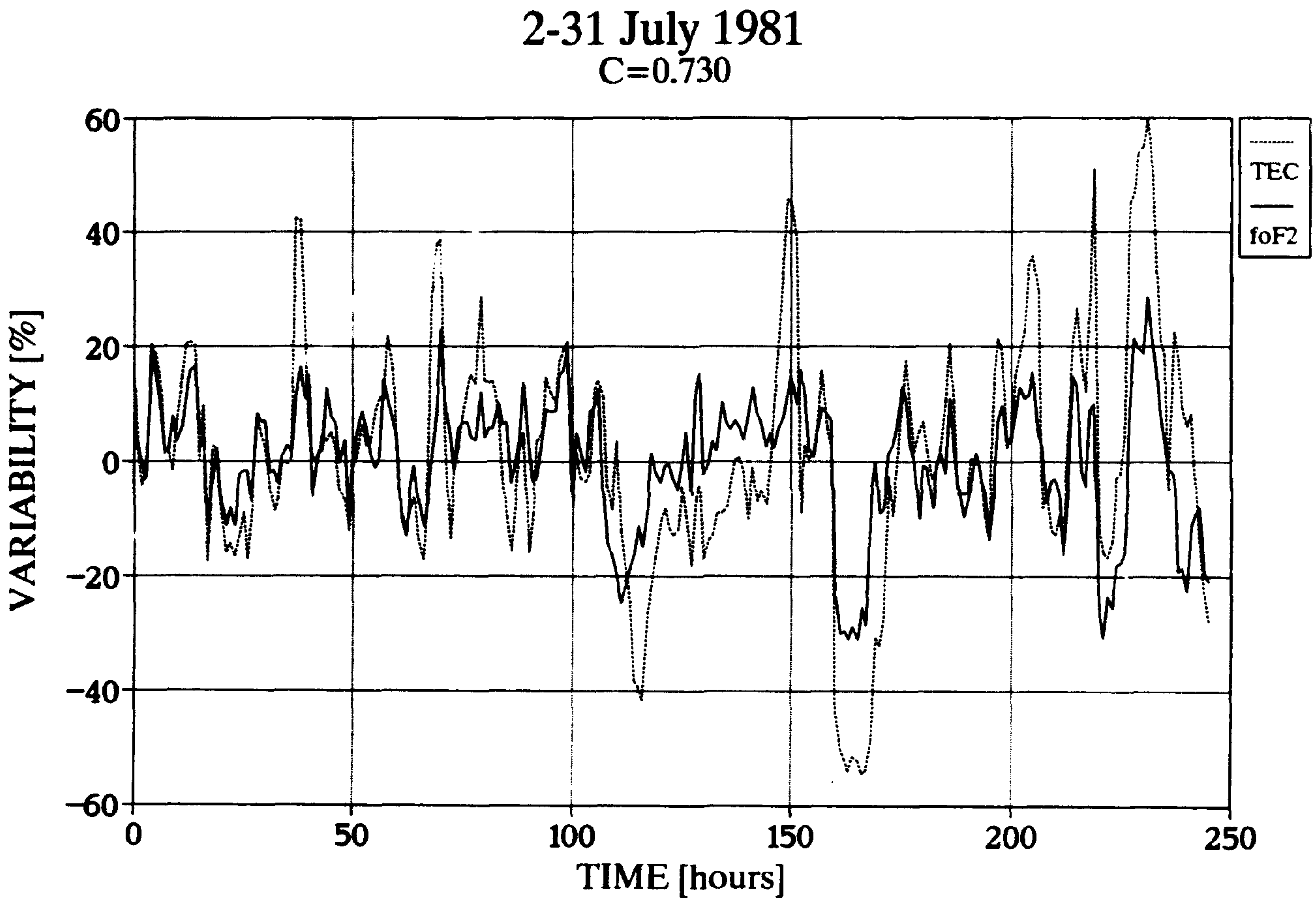

1-31 May 1980
100
80
60
40
20
0
−20
−40
−60
−80
−100
VARIABILITY [%]
0
100
200
300
400
500
600
TIME [hours]
TAU

Fig B-20



2-31 July 1981
C=0.730
TEC
foF2
VARIABILITY [%]
TIME [hours]
60
40
20
0
−20
−40
−60
0
50
100
150
200
250

Fig B-21

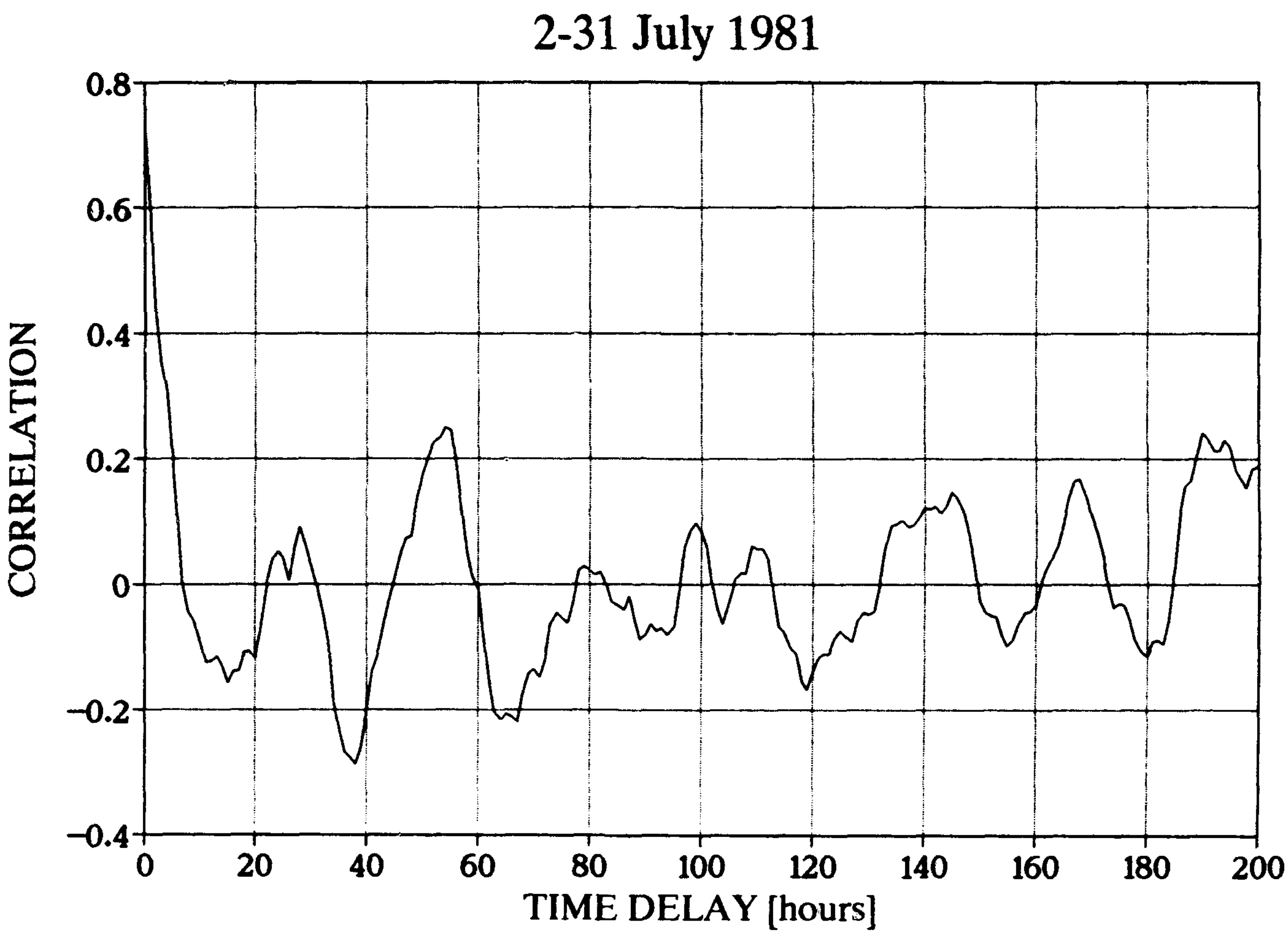
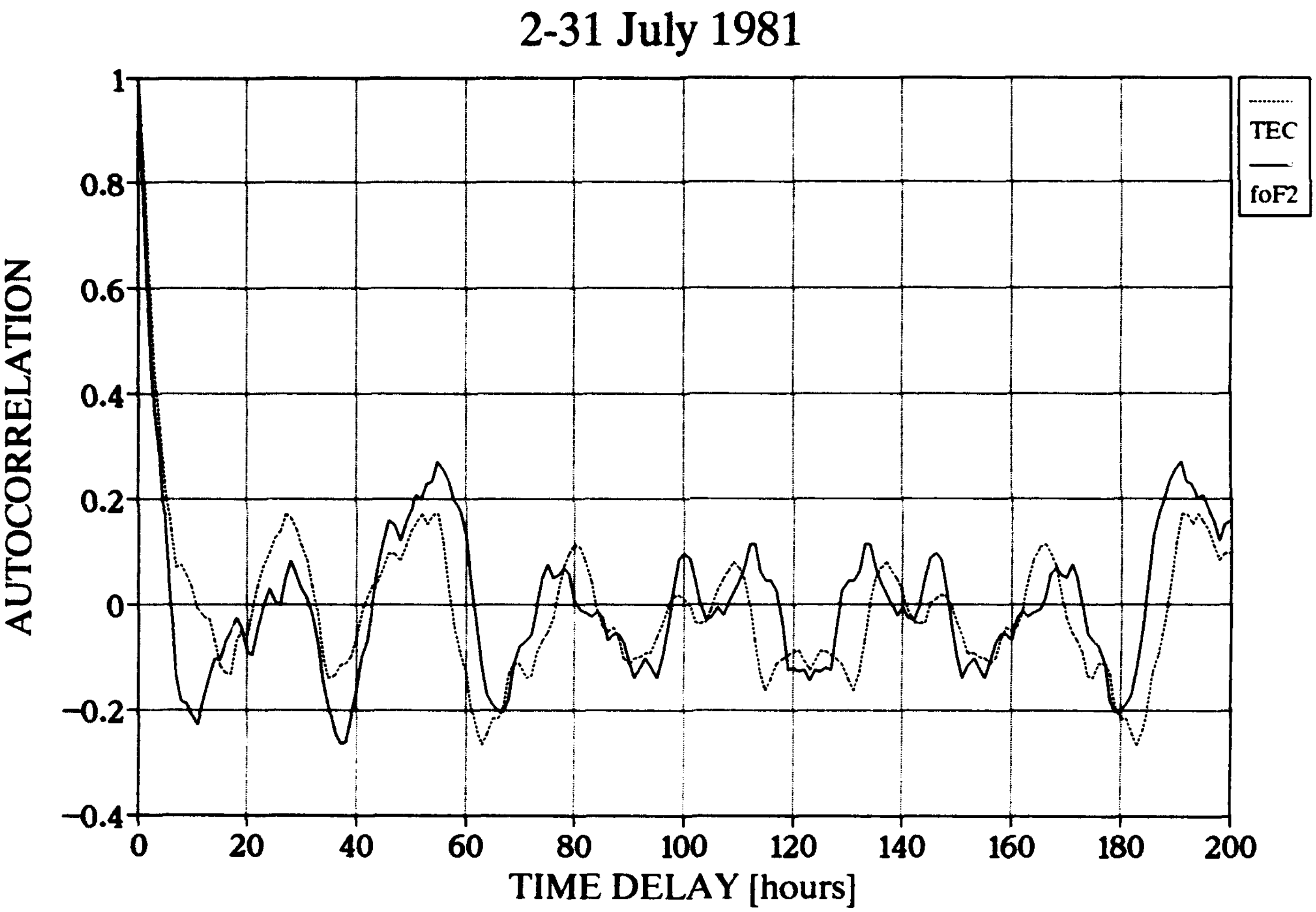

2-31 July 1981
0.8
0.6
0.4
0.2
0
-0.2
-0.4
CORRELATION
0
20
40
60
80
100
120
140
160
180
200
TIME DELAY [hours]

Fig B-22



2-31 July 1981
AUTOCORRELATION
TIME DELAY [hours]
TEC
foF2
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
0
20
40
60
80
100
120
140
160
180
200

Fig B-23

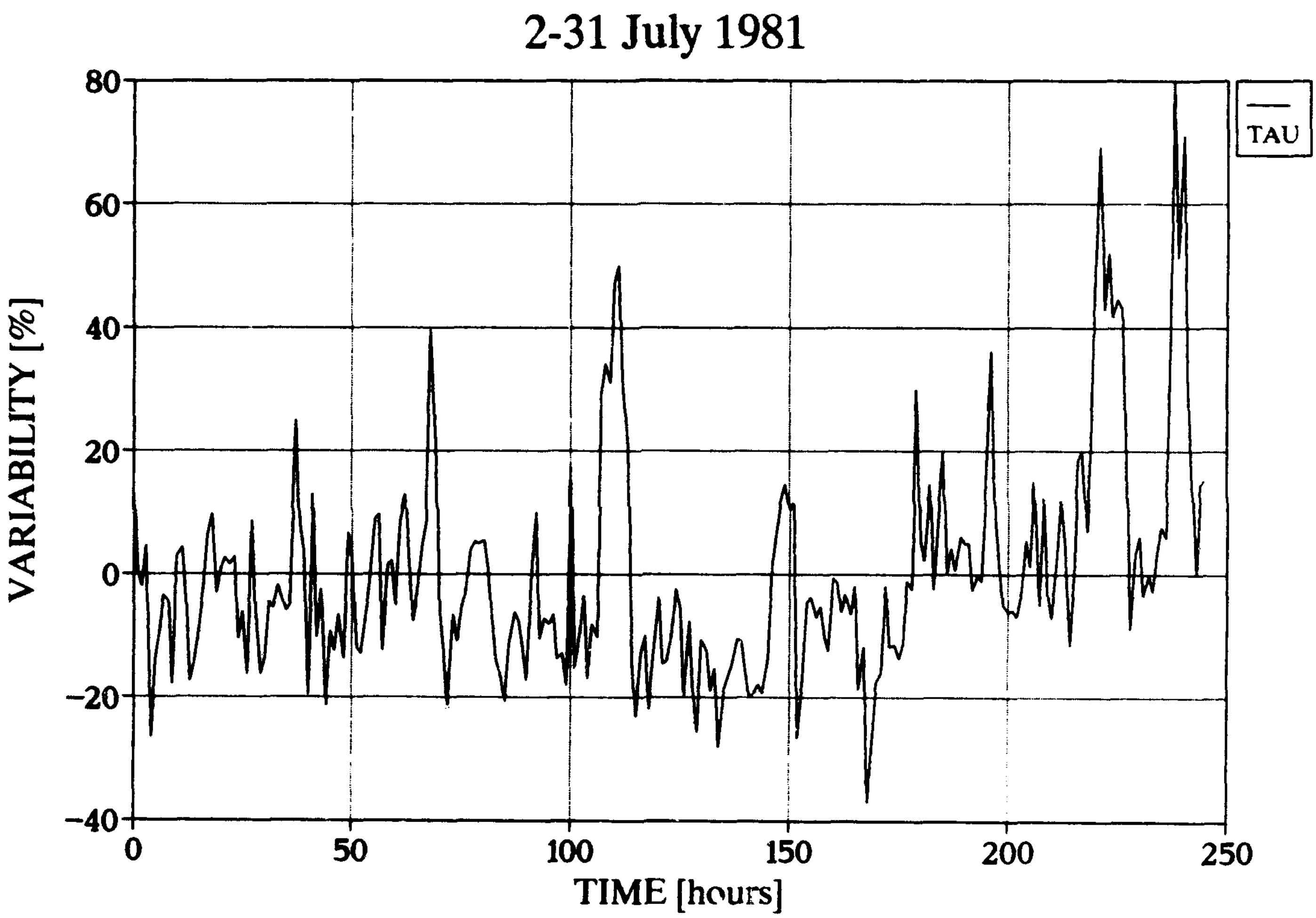

2-31 July 1981
80
60
40
20
0
−20
−40
VARIABILITY [%]
0
50
100
150
200
250
TIME [hours]
TAU

Fig B-24

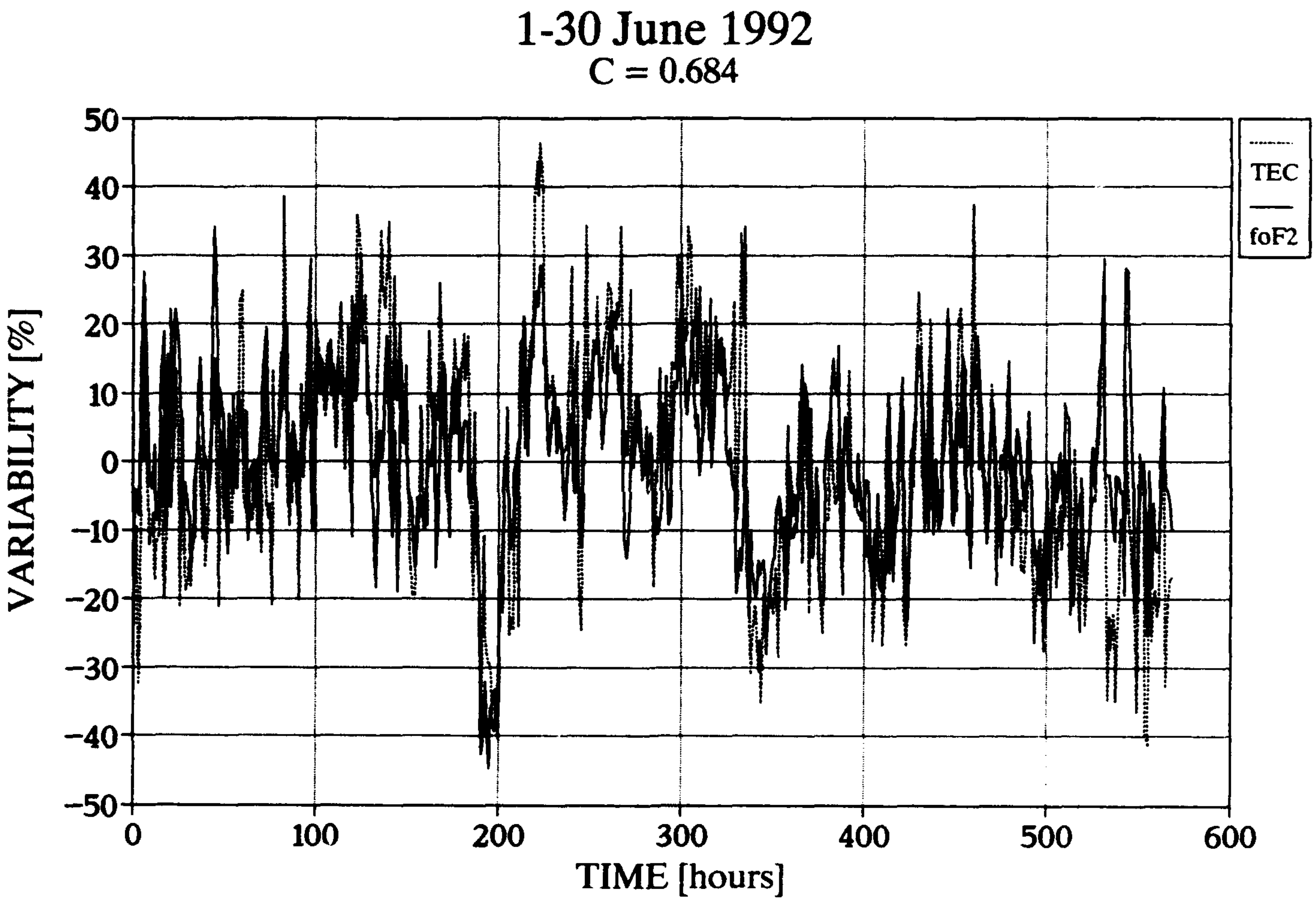

1-30 June 1992
C = 0.684
VARIABILITY [%]
50
40
30
20
10
0
−10
−20
−30
−40
−50
0
100
200
300
400
500
600
TIME [hours]
TEC
foF2

Fig B-25

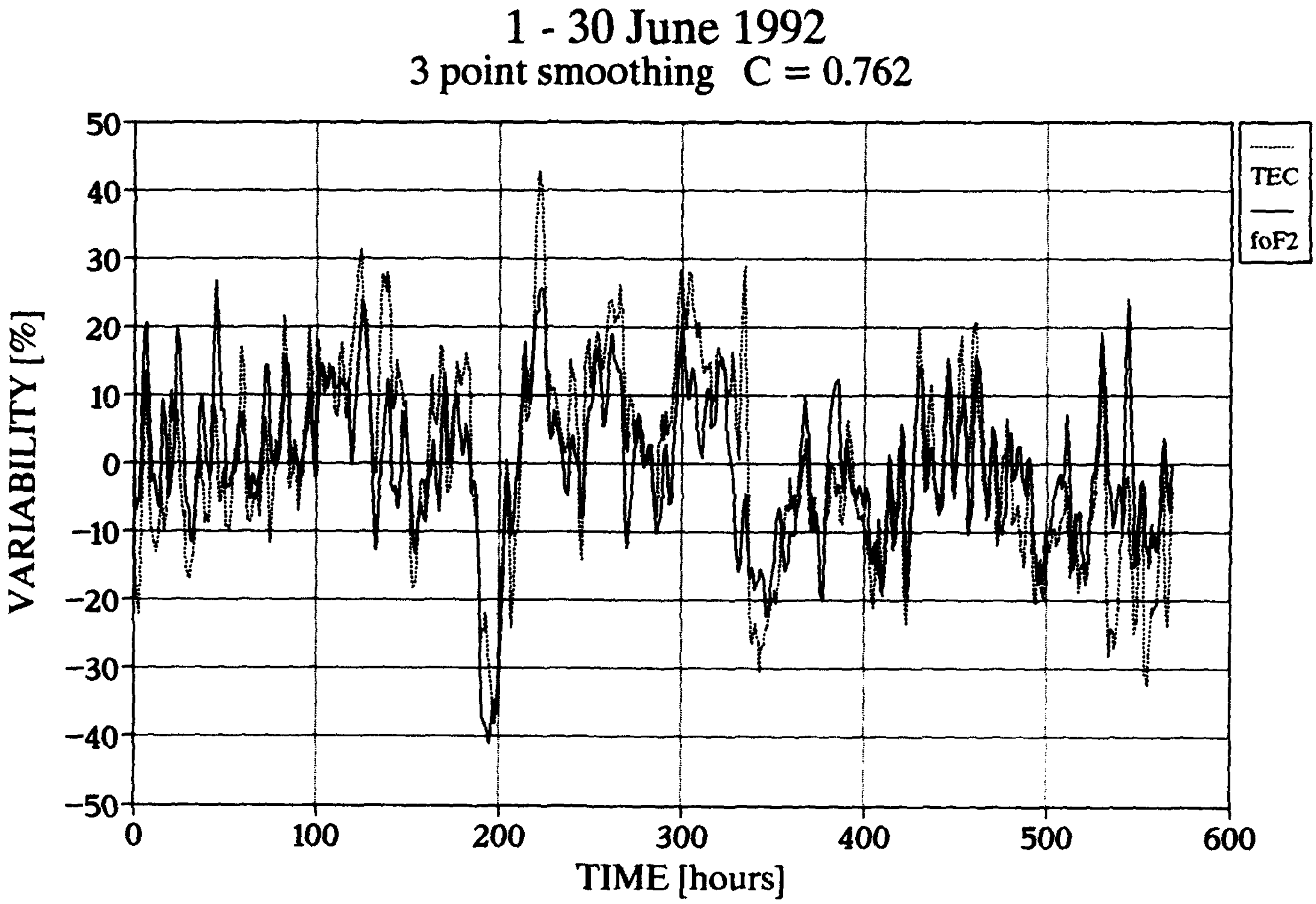

1 - 30 June 1992
3 point smoothing C = 0.762
VARIABILITY [%]
TIME [hours]
TEC
foF2
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
100
200
300
400
500
600

Fig B-26

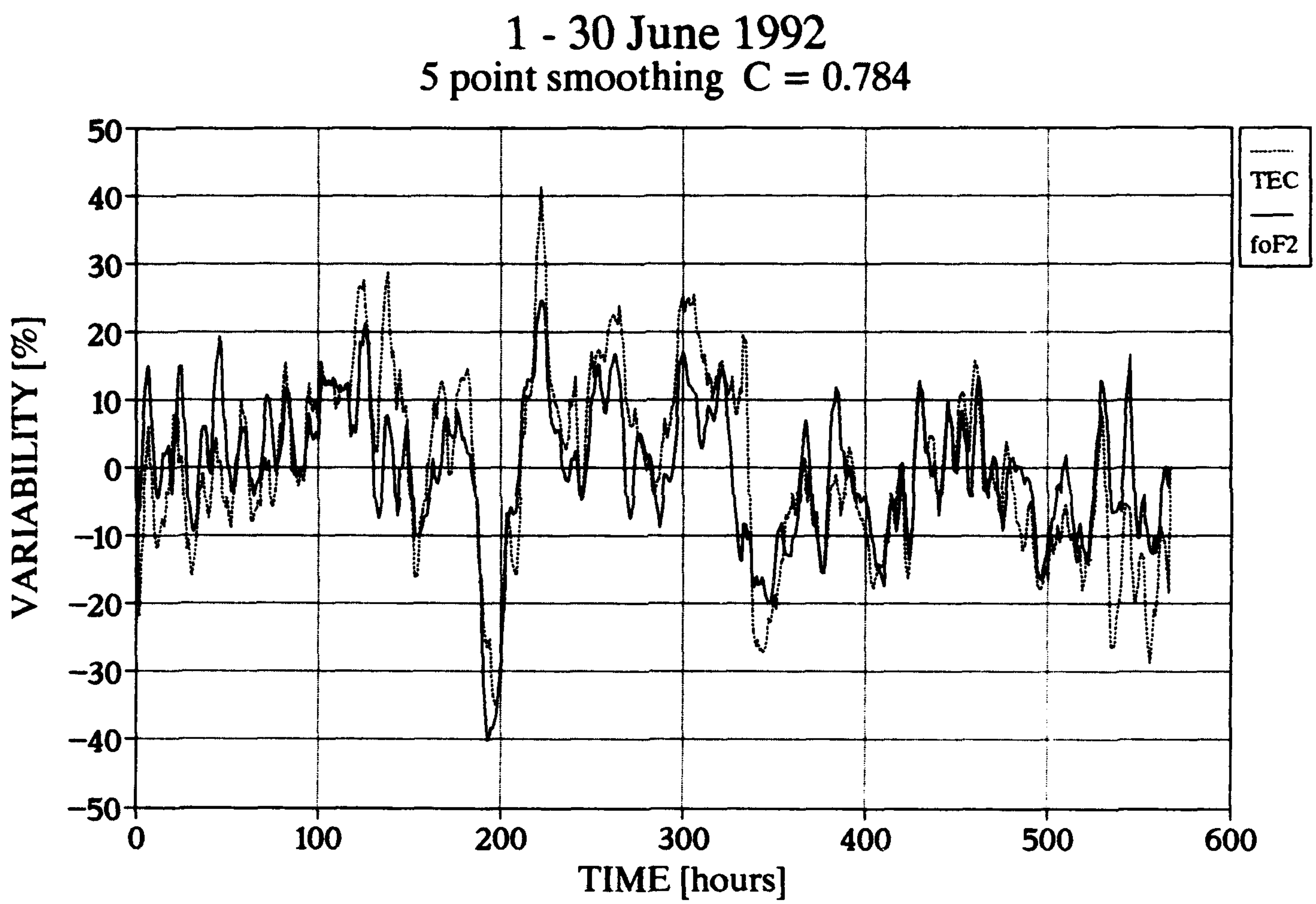

1 - 30 June 1992
5 point smoothing C = 0.784
TEC
foF2
VARIABILITY [%]
TIME [hours]
50
40
30
20
10
0
−10
−20
−30
−40
−50
0
100
200
300
400
500
600

Fig B-27

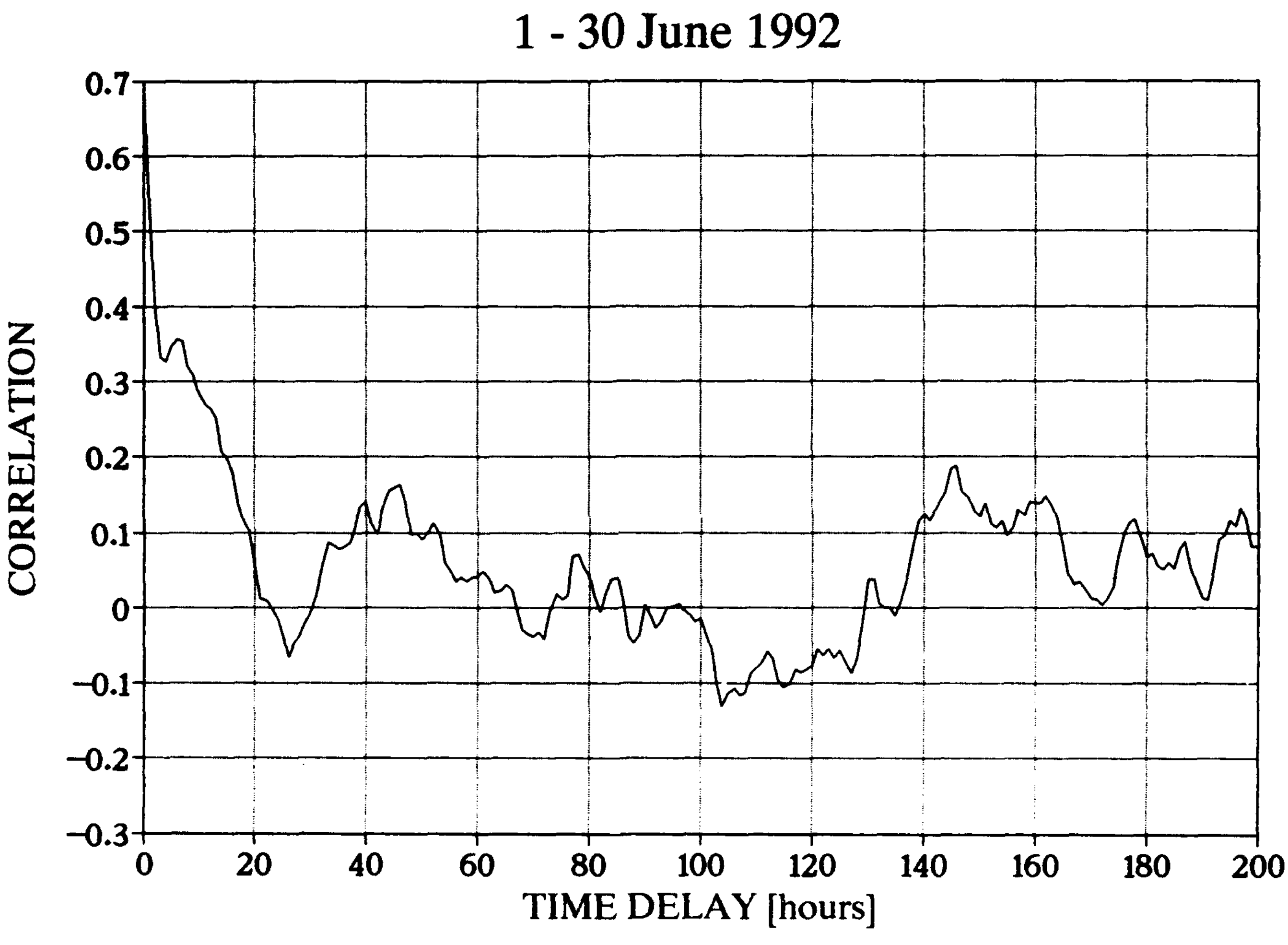

1 - 30 June 1992
CORRELATION
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
0
20
40
60
80
100
120
140
160
180
200
TIME DELAY [hours]

Fig B-28

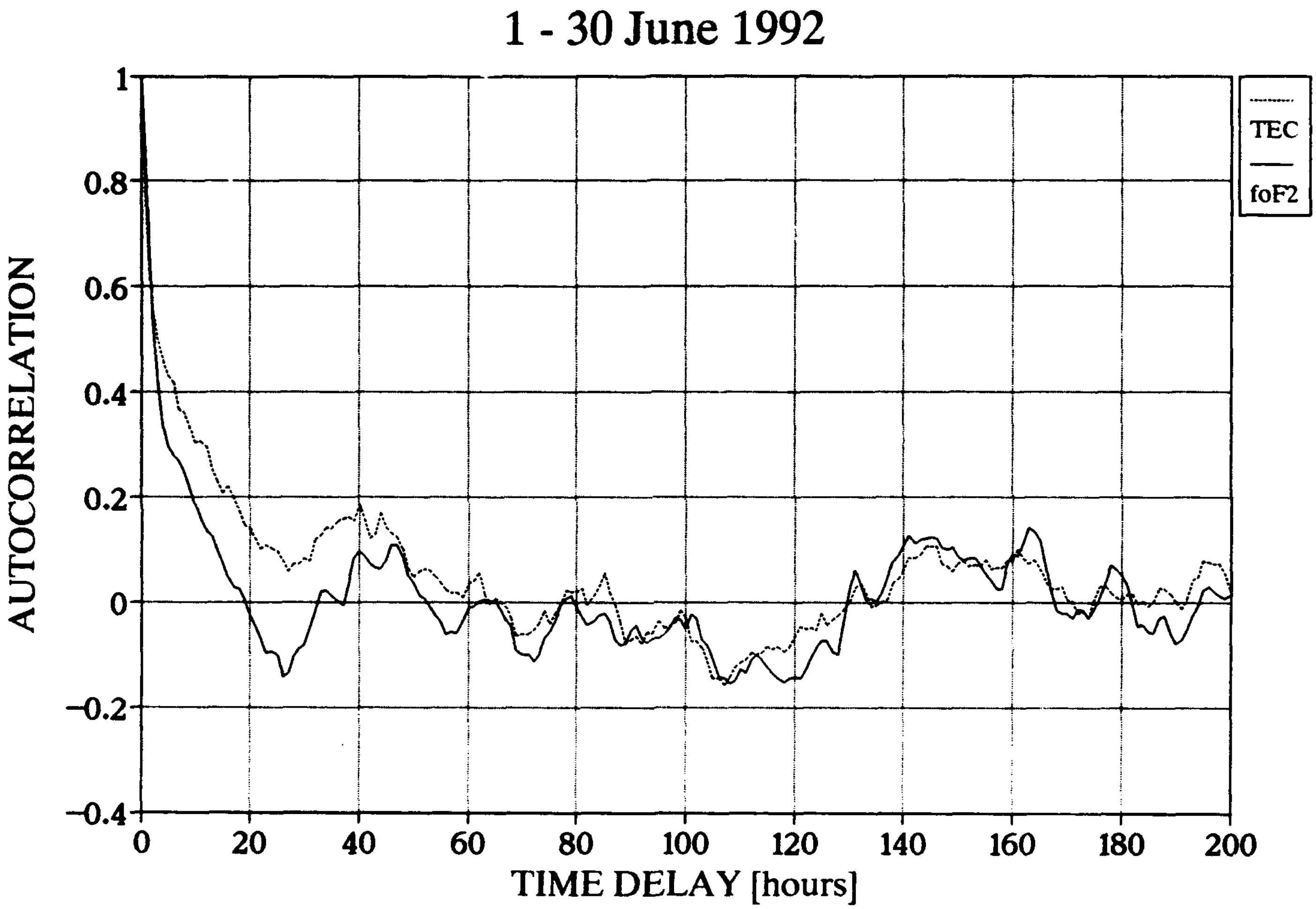

1 - 30 June 1992
AUTOCORRELATION
TIME DELAY [hours]
TEC
foF2
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
0
20
40
60
80
100
120
140
160
180
200

Fig B-29

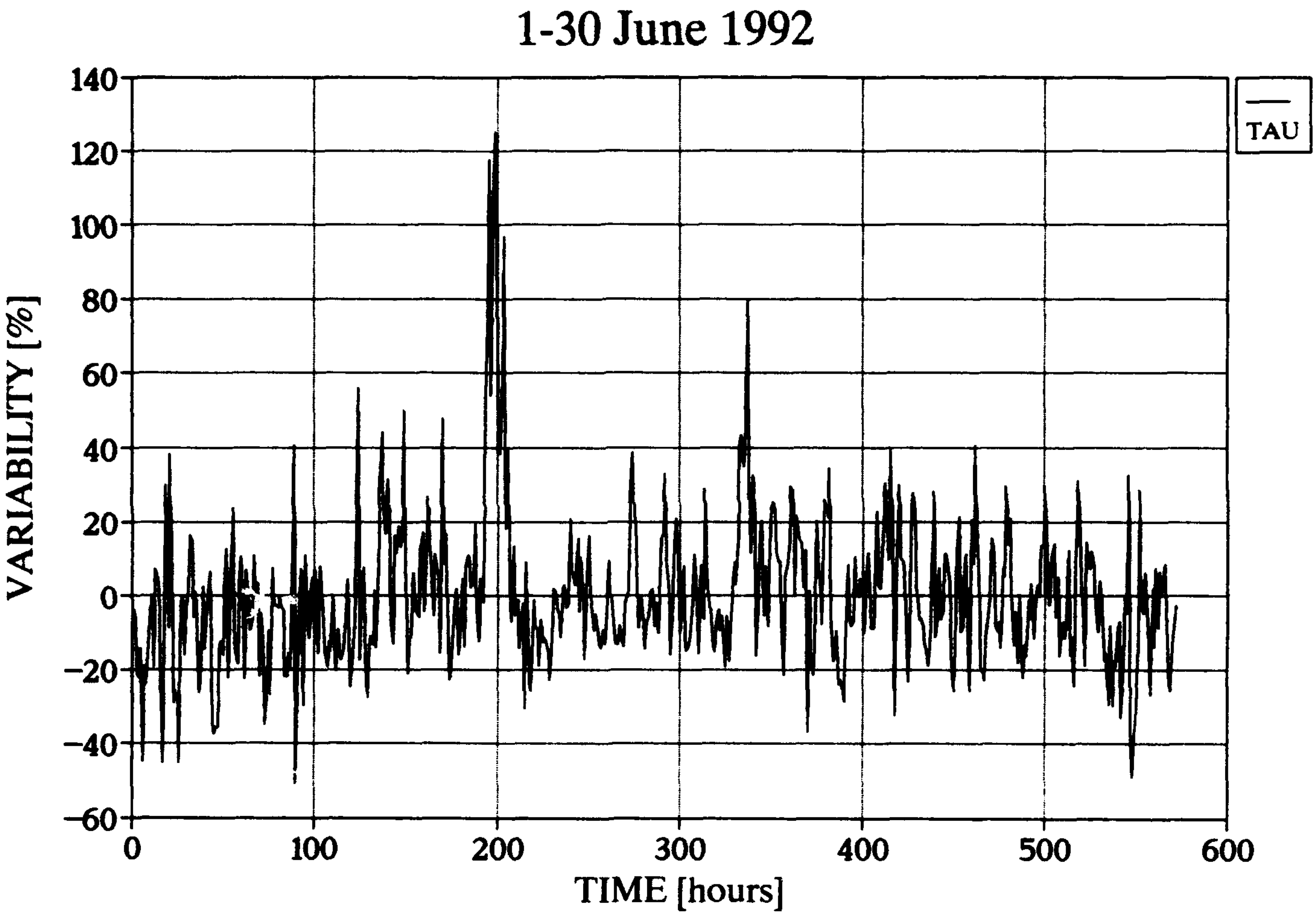
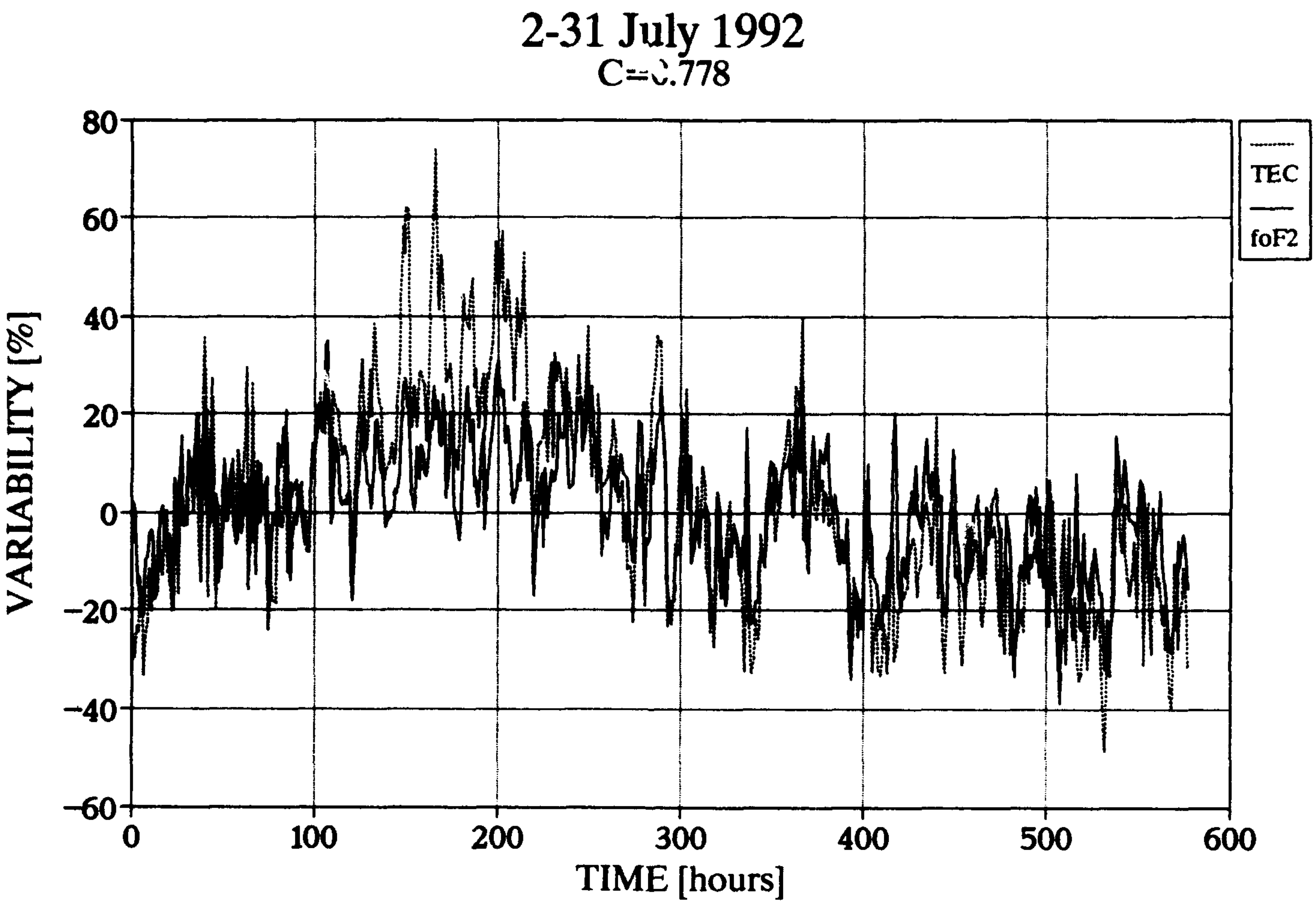

1-30 June 1992
140
120
100
80
60
40
20
0
−20
−40
−60
VARIABILITY [%]
0
100
200
300
400
500
600
TIME [hours]
TAU

Fig B-30



2-31 July 1992
C=0.778
TEC
foF2
VARIABILITY [%]
TIME [hours]
80
60
40
20
0
-20
-40
-60
0
100
200
300
400
500
600

Fig B-31

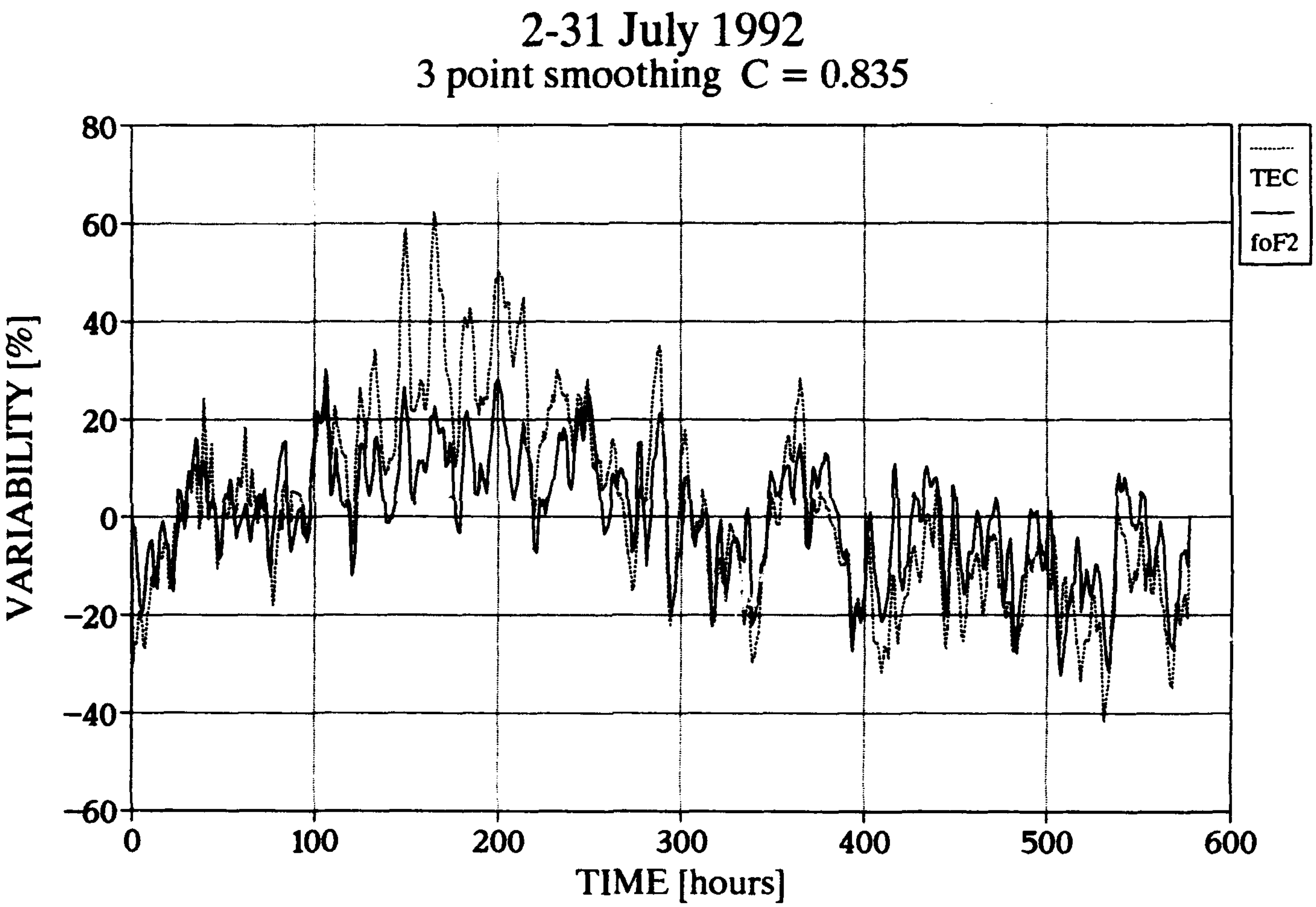
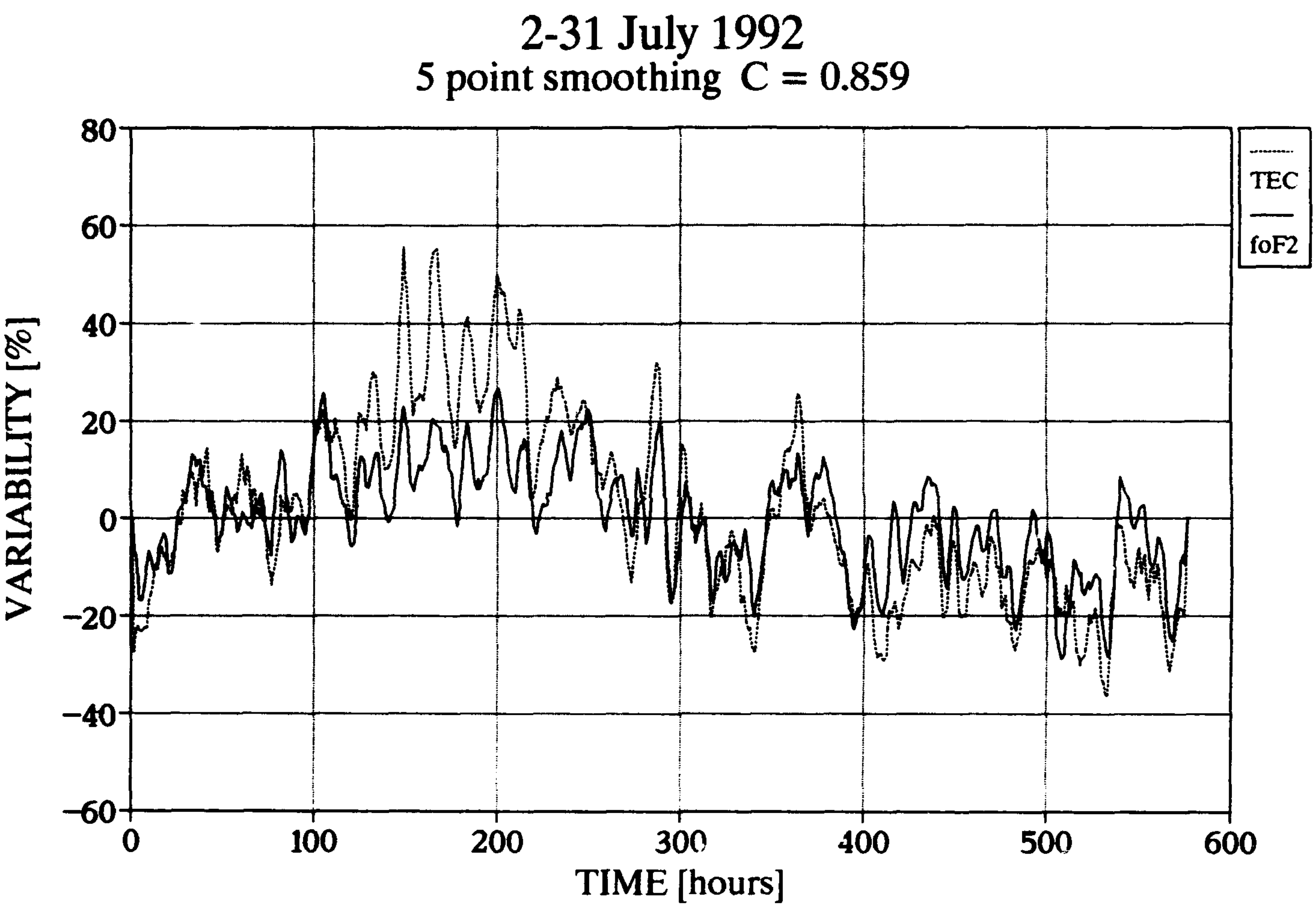

2-31 July 1992
3 point smoothing C = 0.835
TEC
foF2
VARIABILITY [%]
TIME [hours]
80
60
40
20
0
-20
-40
-60
0
100
200
300
400
500
600

Fig B-32



2-31 July 1992
5 point smoothing C = 0.859
TEC
foF2
VARIABILITY [%]
80
60
40
20
0
−20
−40
−60
0
100
200
300
400
500
600
TIME [hours]

Fig B-33

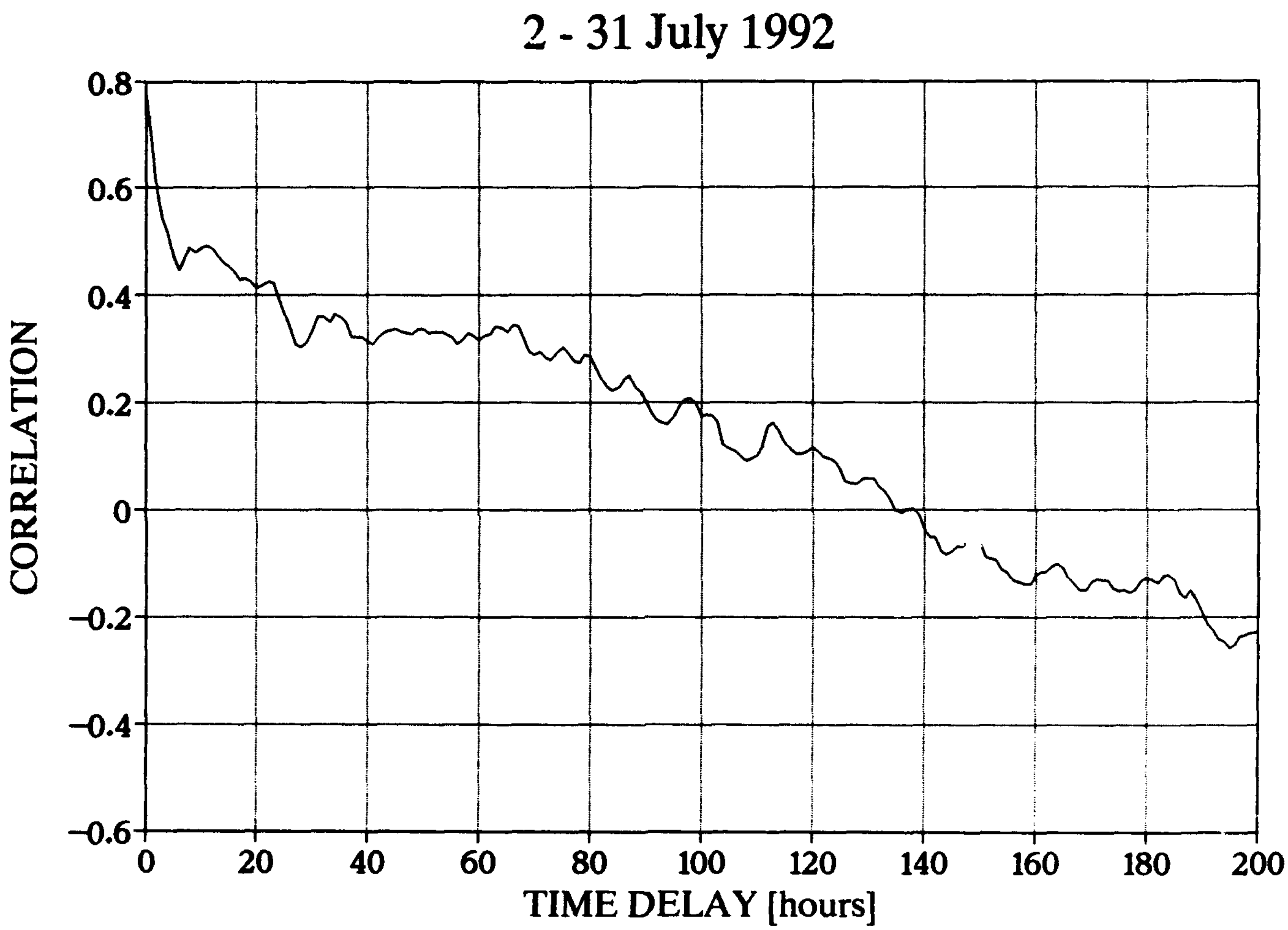

2 - 31 July 1992
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
CORRELATION
0
20
40
60
80
100
120
140
160
180
200
TIME DELAY [hours]

Fig B-34

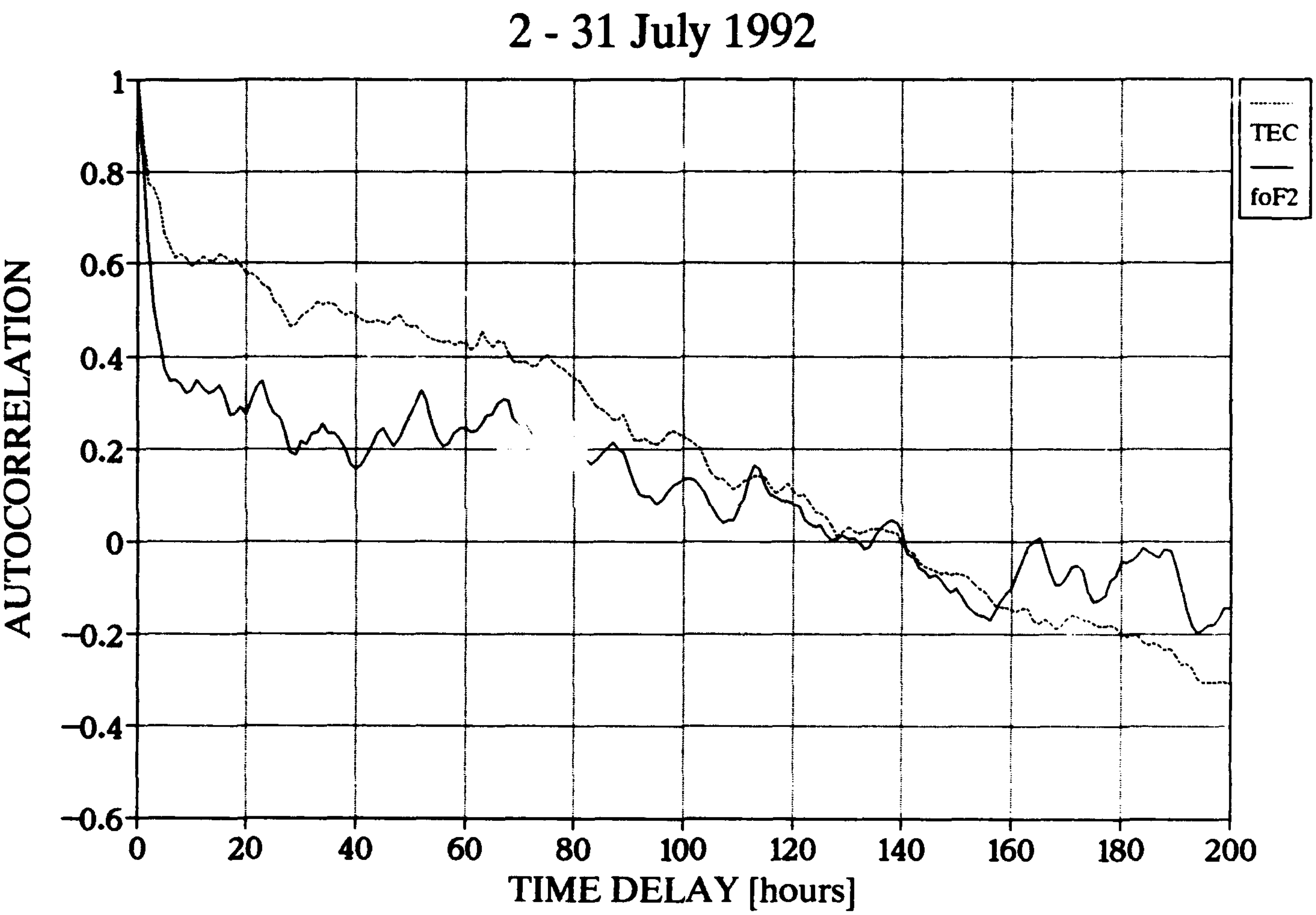

2 - 31 July 1992
AUTOCORRELATION
TIME DELAY [hours]
TEC
foF2
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
0
20
40
60
80
100
120
140
160
180
200

Fig B-35

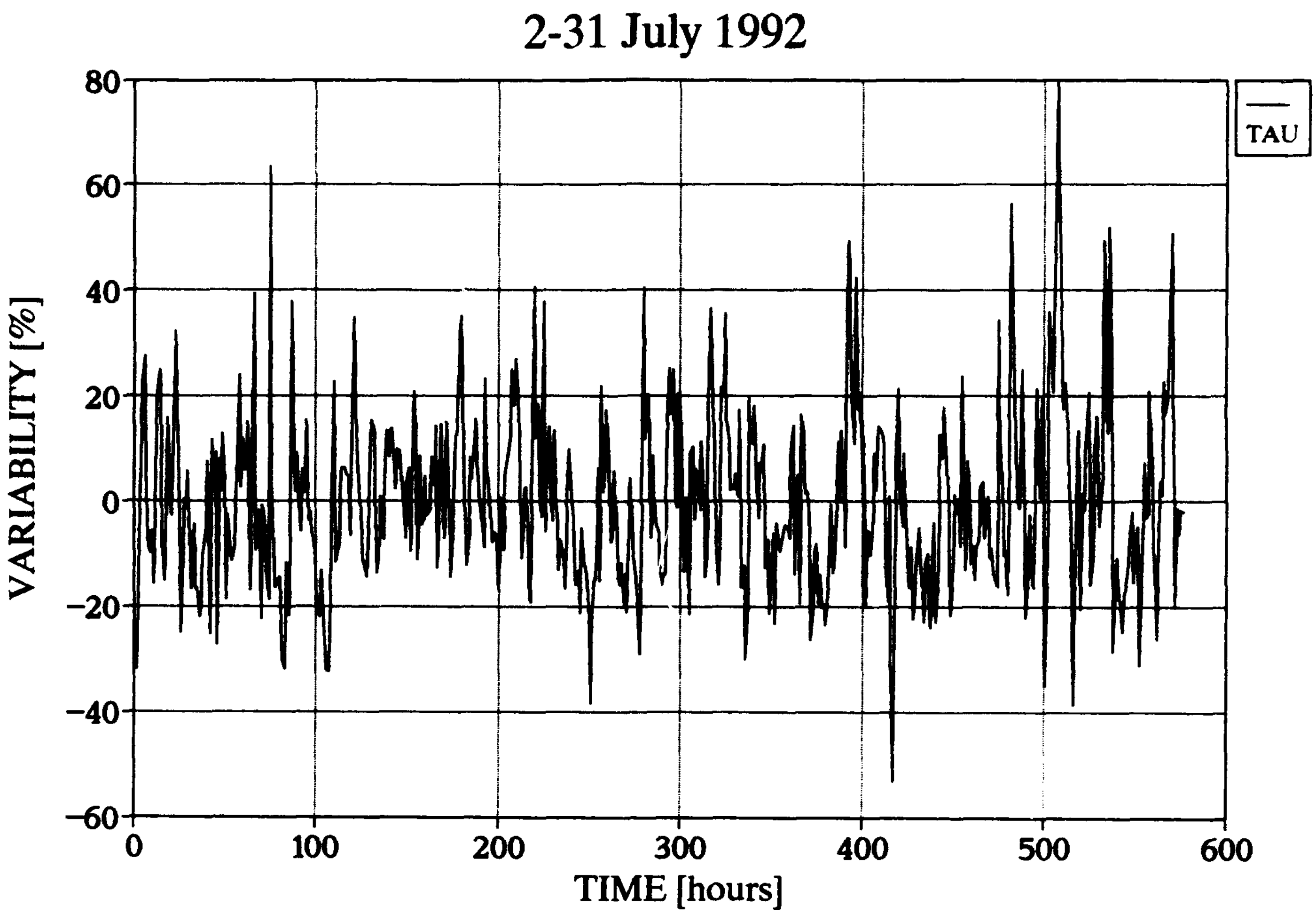

2-31 July 1992
TAU
VARIABILITY [%]
TIME [hours]
80
60
40
20
0
−20
−40
−60
0
100
200
300
400
500
600

Fig B-36

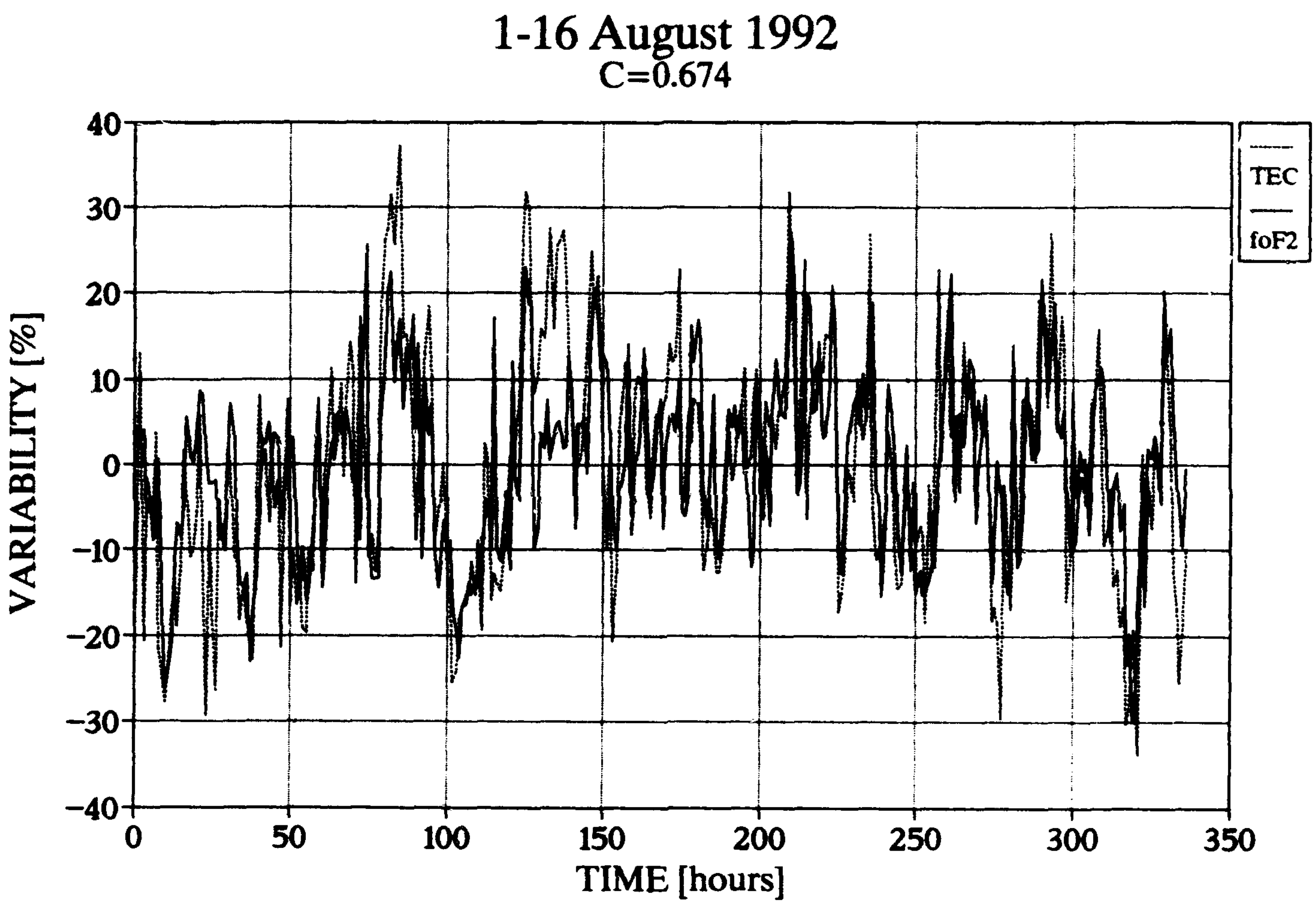

1-16 August 1992
C=0.674
40
30
20
10
0
−10
−20
−30
−40
0
50
100
150
200
250
300
350
TIME [hours]
VARIABILITY [%]
TEC
foF2

Fig B-37

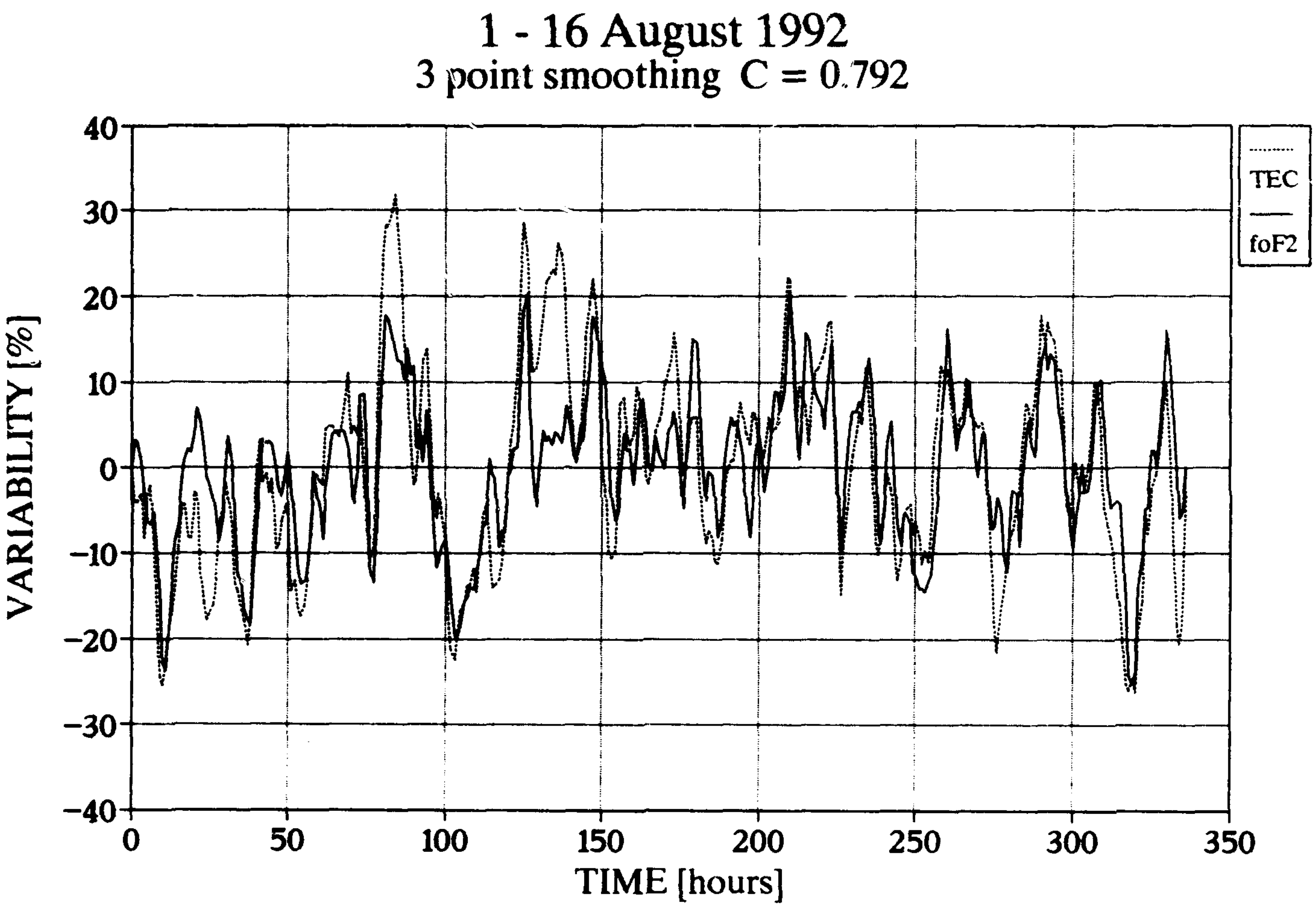

1 - 16 August 1992
3 point smoothing C = 0.792
40
30
20
10
0
−10
−20
−30
−40
VARIABILITY [%]
0
50
100
150
200
250
300
350
TIME [hours]
TEC
foF2

Fig B-38

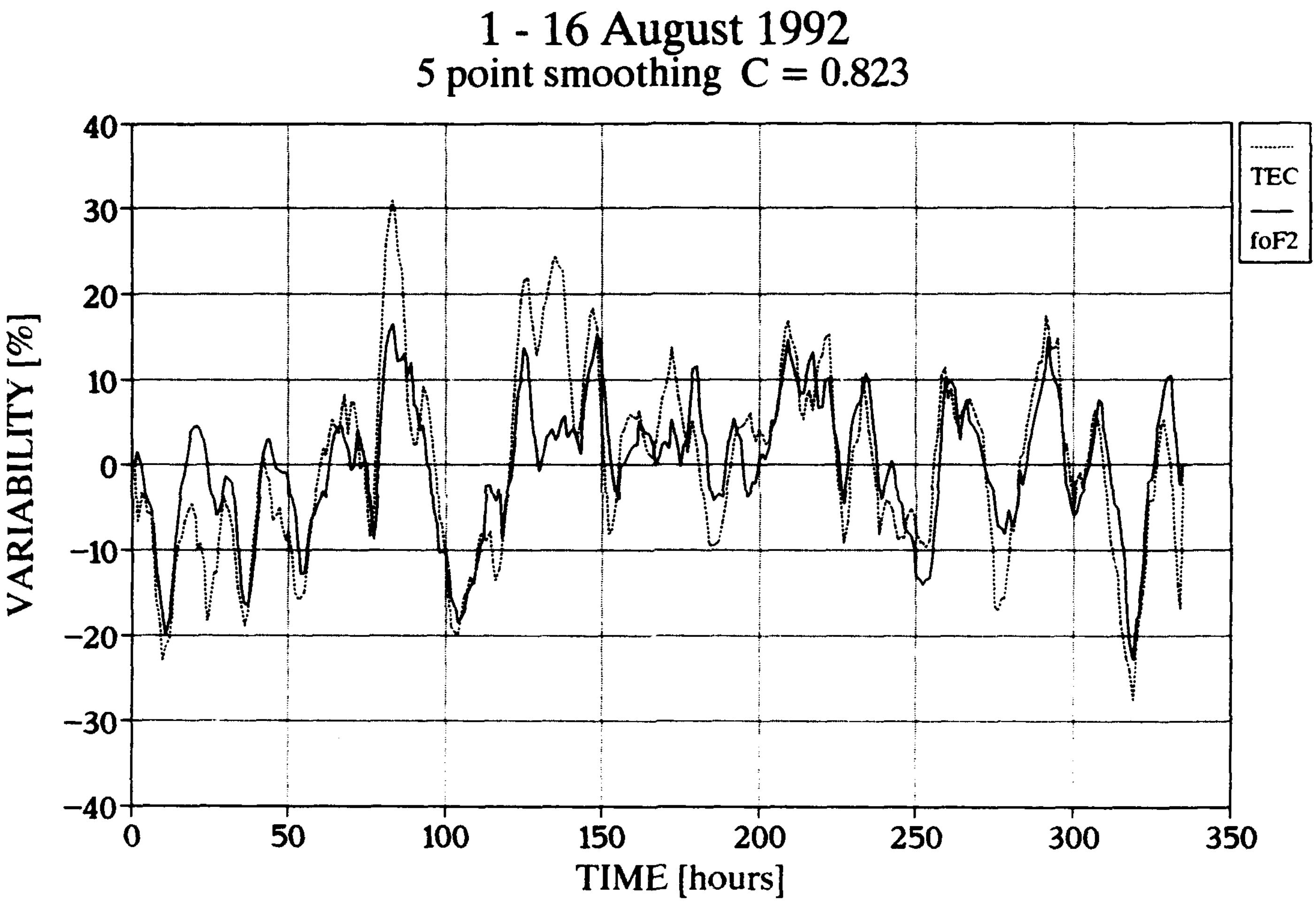
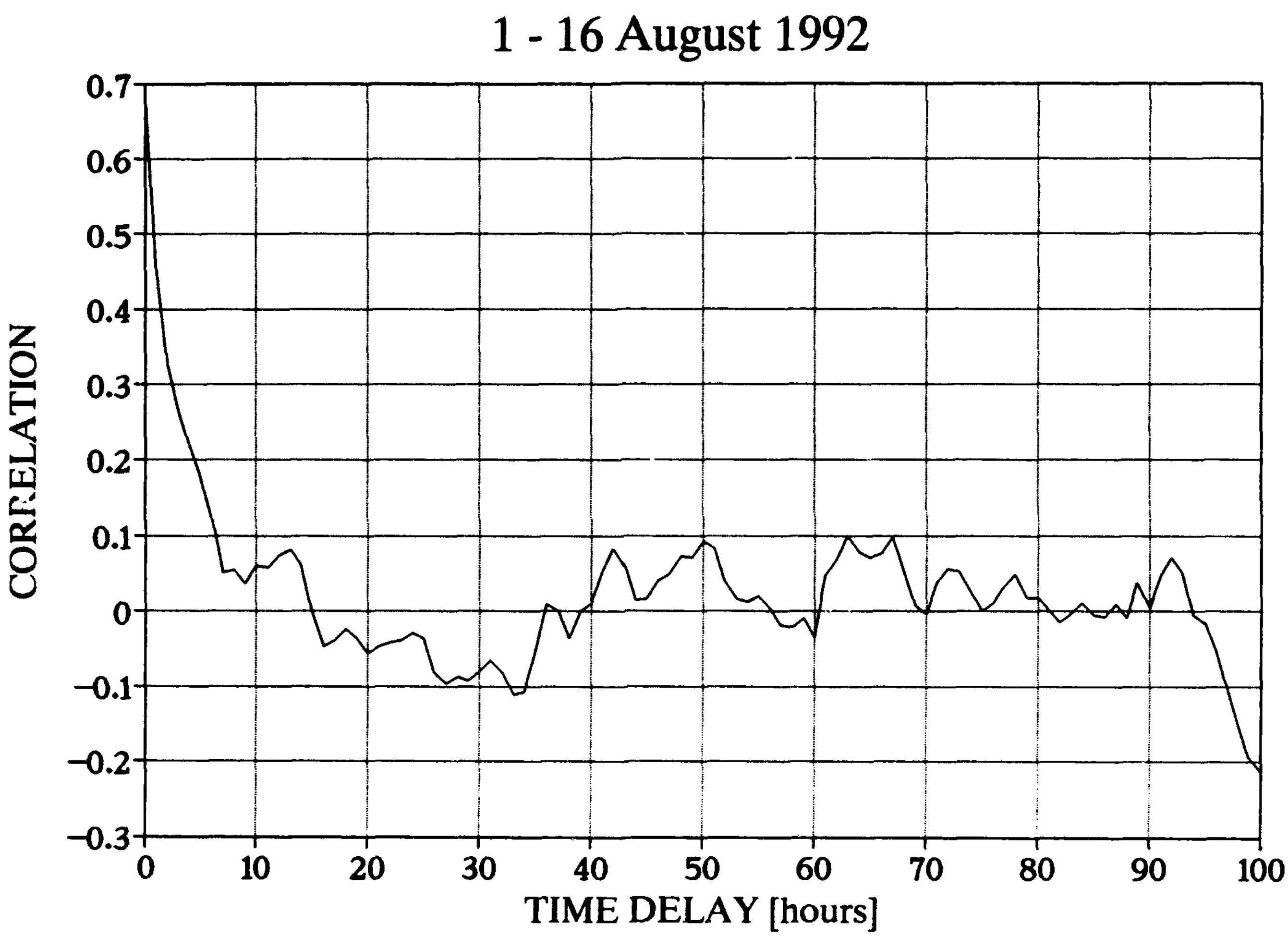
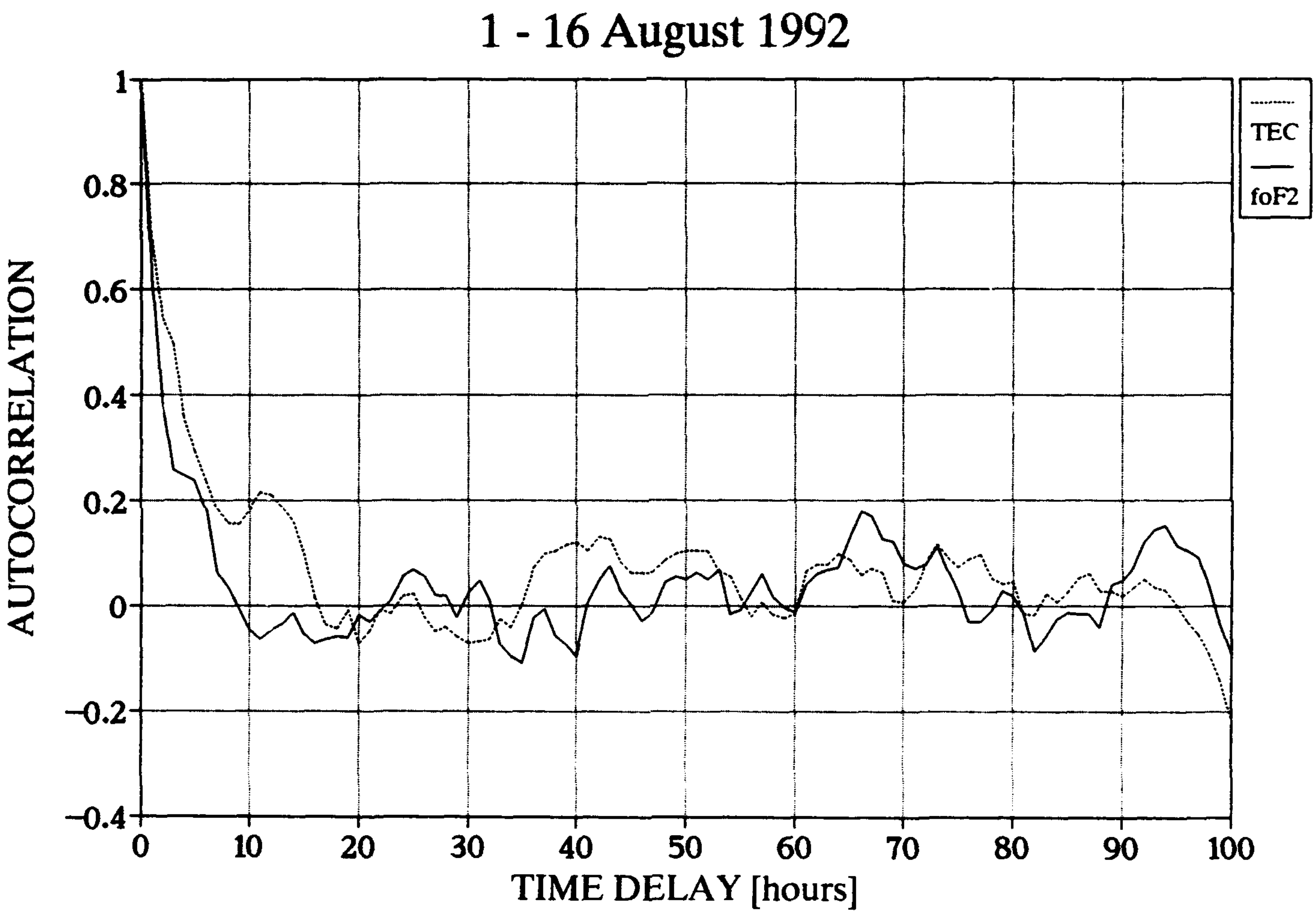

1 - 16 August 1992
5 point smoothing C = 0.823
TEC
foF2
VARIABILITY [%]
TIME [hours]
40
30
20
10
0
−10
−20
−30
−40
0
50
100
150
200
250
300
350

Fig B-39



1 - 16 August 1992
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
CORRELATION
0
10
20
30
40
50
60
70
80
90
100
TIME DELAY [hours]

Fig B-40



1 - 16 August 1992
AUTOCORRELATION
TIME DELAY [hours]
TEC
foF2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0
10
20
30
40
50
60
70
80
90
100

Fig B-41

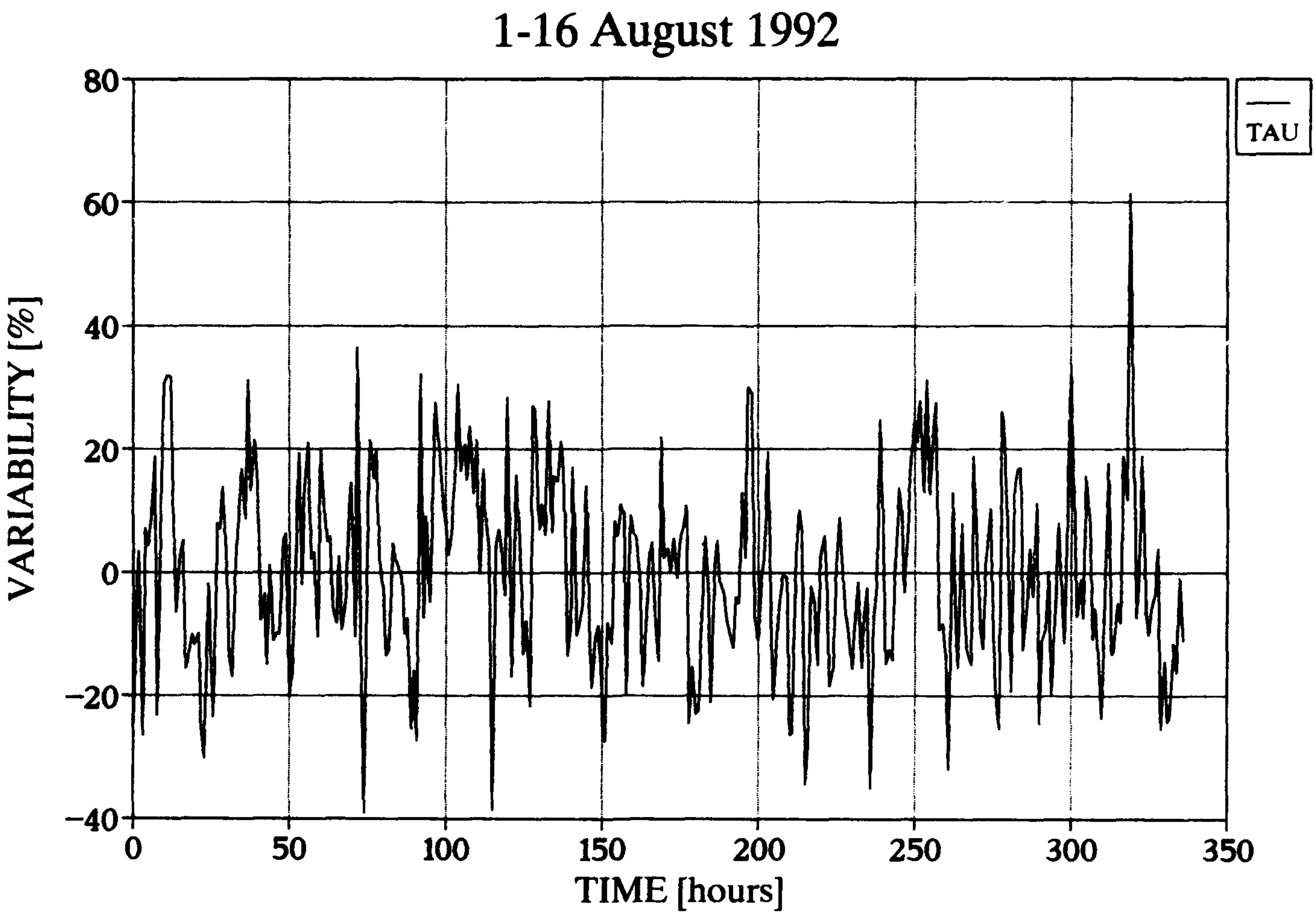

1-16 August 1992
80
60
40
20
0
−20
−40
VARIABILITY [%]
0
50
100
150
200
250
300
350
TIME [hours]
TAU

Fig B-42